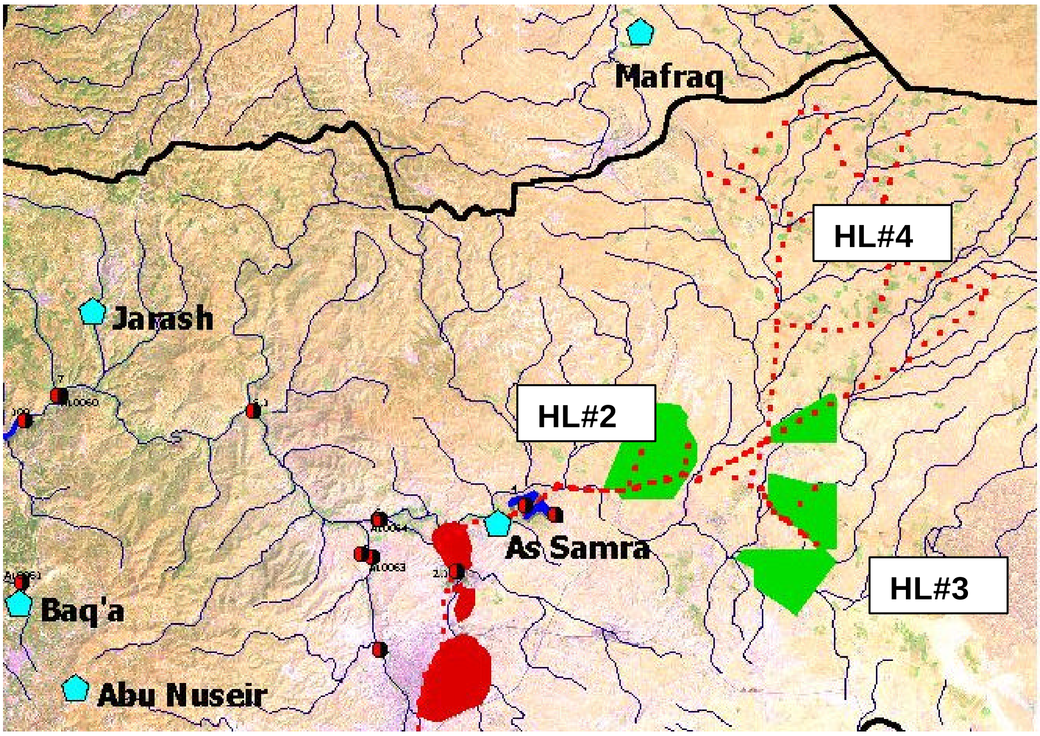
MINISTRY OF WATER AND IRRIGATION
Water Resource Policy Support

WATER REUSE COMPONENT



Location of Irrigation Options in the Amman-Zarqa Highlands

PRE-FEASIBILITY STUDY
WATER REUSE FOR AGRICULTURE AND/OR FORESTRY IN THE AMMAN-ZARQA HIGHLANDS

FINAL DRAFT

December 2000

The Water Resource Policy Support activity is supported by
the United States Agency for International Development (USAID) through a
Contract with Associates in Rural Development Inc.(ARD:
USAID/ARD Contract No. LAG-I-00-99-00018-00, Delivery Order No. 800

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ABBREVIATIONS

ARD	Associates in Rural Development
AZB	Amman-Zarqa Basin
BMP	Best Management Practices
BOD_5	Biochemical Oxygen Demand, Five Day
COD	Chemical Oxygen Demand
DA	Development Area
DO	Dissolved Oxygen
ECC	Economic Consultative Council
FCC	Fecal Coliform Count
GAP	Good Agricultural Practices
GIS	Geographic Information System
GPS	Global Positioning System
GTZ	German Technical Cooperation
HL	Highlands
HRZ	Hashemite-Rusefieh-Zarqa area
IAS	Irrigation Advisory Service
IRG	International Resources Group
JICA	Japanese International Cooperation Agency
JV	Jordan Valley
JVA	Jordan Valley Authority
Km^2	Square Kilometers
KTR	King Talal Reservoir
LEMA	Lyonaise des Eaux Management-Amman
LIMS	Laboratory Information Management System
m^3	Cubic meter
M&I	Municipal and Industrial
MCM	Million cubic meters
MOA	Ministry of Agriculture
MOH	Ministry of Health
MWI	Ministry of Water and Irrigation
NCARRT	National Center for Agriculture Research and Technology Transfer
NIR	Net Irrigation Requirements
NPW	Net Present Worth
NRA	Natural Resources Authority
RA	Rapid Appraisal
RS	Remote Sensing
SO	Stage Office
SS	Suspended Solids
TDS	Total Dissolved Solids
TO	Task Order
UFW	Unaccounted for Water
USAID	United States Agency for International Development
WAJ	Water Authority of Jordan
WRPS	Water Resources Policy Support
WSP	Waste Stabilization Ponds
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

This draft document reports on the pre-feasibility investigations of using reclaimed water from the As Samra wastewater treatment plant for irrigated agriculture/forestry at three sites in the highlands of the Amman-Zarqa Basin. The economic analysis is reportedly separately (Shaner, 2000). This report presents the basic characterization of the three options considered, the preliminary conclusions, and summaries of the supporting investigations and analyses.

Three basic options for use of As Samara effluent for irrigated agriculture/forestry in the highlands of the Amman-Zarqa Basin were identified for investigation. These were:

- Highlands irrigation project (Option HL#2);
- Wadi Dhuleil and Khalidiyyeh irrigation project (Option HL#3); and
- Highlands irrigation distribution network (Option HL#4).

It was anticipated from the outset that the options would be relatively expensive, with the most expensive being located furthest from the treatment plant and highest in elevation. The unit costs for developing and operating each option is found to be even higher than anticipated. The range of initial irrigation infrastructure costs is $25,000-50,000/ha, and the total costs of delivering water to field level are estimated at $0.30-0.80/ m^3.

Given these very substantial costs, the preliminary conclusion is that the options under consideration, or indeed the general concept of pumping reclaimed water into the highlands for agricultural use, do not appear economically viable unless the resulting savings in groundwater are given high values and highly-profitable cropping regimes are developed. However, there may be only limited potential to offset costs through potential savings in ground water; for example, the present 2.5 MCM of groundwater used at HL#3 is already saline (2500-3000-mg/l).

From the investigation and analysis to date, the key characteristics for each option, in terms of water requirements and capital costs are presented in Table 1.

Table 1. Key characteristics of highlands irrigation reuse options

	Irrigable Area (dunums)	Water Requirement (m^3)	Total** Capital (JD)	Per*** m^3 (fils/m^3)	Per Dunum* (JD/dunum)	Per Ha ($US/ha)
HL#2a	10,200	12,330,000	19,100,000	210	1,873	26,216
HL#3	8,000	9,600,000	28,200,000	380	3,525	49,350
HL#4	n/a	10,000,000	44,300,000	570	n/a	n/a

*based on gross irrigable area n/a = not available
**irrigation structures only , excluding filtration /disinfection
***cost (capital/operating) of delivery to field

Summaries of Investigations & Analyses

Highlands irrigation project (HL#2 & HL#2a)

Option HL #2, which was identified by Harza (1997), would require the development of a new site for irrigation. It is located approximately 5-km East and North of As Samra. Investigation of the land resources found that most of the land in the area is not suitable for sustaining irrigated agriculture, especially with the relatively saline supplies of reclaimed water. The option was relocated to the west onto lands that are more sustainable. This revised option is identified as HL#2a.

The conceptual project is based on a large tract of irrigable land extending northwards from the settlement of As Samra, along the rail-line. The gross area to be irrigated is approximately 10,200-dunums (1020-ha). The required infrastructure would consist of a pumping station at the outlet of the wastewater treatment plant, a conveyance pipeline and eight reservoirs, serving each of the blocks of the project. The application systems would be trickle.

Wadi Dhuleil and Khalidiyyeh irrigation project (HL#3)

Option HL#3 is located approximately 14-km east of As Samra. The initial concept was to supply the existing irrigation project at Dhuleil with a new source of water, thereby reducing the effect of this project's wells on the groundwater, and, possibly, expanding into two further phases to the north. The source of groundwater for the existing project is no longer viable having become relatively saline and, reportedly, limited. Investigation of the land resources, as will be presented below, determined that the only irrigable land in the vicinity is that which the present project occupies and, therefore, expansion of the option will not be practical beyond the existing project's boundaries.

The gross irrigable land available is approximately 8,000-dunums (800-ha), of which about 4,600-dunums is presently irrigated. Most of the existing infrastructure would have little value in the new project as presently conceived. As with HL#2a, the development of this option would require a pumping plant at the wastewater treatment facility, a conveyance line, storage reservoirs (7), distribution networks and trickle irrigation application systems.

Highlands irrigation distribution network (HL#4)

Option HL#4 is located in the upper Northeastern area of the Zarqa drainage basin, and is intended to convey water to existing irrigated farms to exchange for groundwater supplies. Clearly this is a very expensive option, involving a 40-km long pipeline to a storage reservoir located at an altitude of 300-m above As Samara, but it was considered important to investigate if the value of the groundwater saved is high enough.

Reclaimed Water Resources

It is anticipated that nearly 50 MCM/annum of additional effluent will be generated from As Samra by the year 2010. Approximately 50% of this volume of effluent could be absorbed by highland agriculture/forestry options such as those studied here, if they are found to be viable. Future Working Papers will consider options for additional reuse in the Zarqa valley and the Jordan Valley, which currently absorb all of the effluent.

It is anticipated that the quality of the effluent being supplied to users will comply with the Jordanian Standards for discharge to wadis. The Total Nitrogen content is specifically set to be lower than 30-mg/l, which is much lower than the current Jordanian standard of 50mg/l. Further details on anticipated quality of effluent is presented in the Water Reuse Component Working Paper "Characterization of Wastewater Effluent in the Amman-Zarqa basin" (MWI/ARD, 2000b).

Further treatment of the reclaimed water is not anticipated for the three options considered in this report, although disinfection will be advisable, and filtration at the field level will be required for the trickle application systems.

Water Requirements

Considering the agro-climatic characteristics of the area under study, the constraints placed on crop selection due to the Jordanian Standards, the viability of irrigating with equipment that complies with good management practices, and the sensitivity of specific crops to the quality of the water supply, there is a limited choice of available crops for the options studied. The crop-water needs under a relatively flexible water supply system, for various crops with shallow, medium and deep rooting systems, and for crop mixes, were examined. From this, the peak gross irrigation requirement was determined to be 1.1-lps/ha, and the total gross annual crop water requirements were 890- m^3/dunum (8,900-m^3/ha), with a further 450-m^3/dunum (4,500-m^3/ha) for leaching.

Overview of Environment & Health

The approach taken in the pre-feasibility design has been to use closed-pipe conveyance, delivery and application systems, along with disinfection of the secondary treated wastewater. Other measures will also be required, including restricting the cropping patterns, and training the field workers. Enforcement of the crop restrictions will be challenging, especially in HL#4.

The major concern that remains with all of these projects is the threat of contamination of the groundwater. The use of efficient application conveyance, delivery and application systems will limit this risk, but leaching of the soil profile is a requirement of irrigated agriculture in this climate. The reclaimed water along with the concentrated salts from the root-zone and any residual fertilizers or pesticides used in agriculture production, are potential contaminants. This issue must be investigated in detail prior to proceeding to implementation.

ACKNOWLEDGMENTS

This report was written by Peter G. McCornick, Ramzi Sabella and Nisreen Haddadin, with support and assistance from many individuals. We would like to specifically acknowledge the valuable contributions of Engs. Yasser Nazzal, Suzan Taha, Edward Qonqor and Naseer Abu Arqoob in supporting the initial investigations and invaluable feedback from first drafts of this report.

The support of the United States Agency for International Development (USAID) Mission in Jordan, and the Associates in Rural Development (ARD, Inc.) team, in Jordan and Vermont, is highly appreciated.

I. INTRODUCTION

This report presents a pre-feasibility level study for developing new irrigated agriculture and/or forestry in the upper basin of the Zarqa wadi. Such developments would utilize the increases in effluent to be generated from the Kherbit As Samra wastewater treatment plant and those from the planned Wadi Zarqa plant.

Concurrent to undertaking this study, the water reuse team is also investigating the present water reuse standards and considering whether changes may need to be made. The findings and recommendations will be reported in a separate Water Reuse Component Working Paper. For the purpose of the investigations reported here, it is assumed that the options presented herein will, at a minimum, comply with the present Jordanian Standards.

OBJECTIVES

The objective of this study is to determine the technical and economic viability of developing irrigated agriculture and/or forestry using the effluent from Kherbit As Samra in the highlands of the Amman-Zarqa basin. The options described herein will be considered as parts of the scenarios for managing water reuse in the Amman-Zarqa basin.

SCOPE & LIMITATIONS

It is assumed that the effluent from Kherbit As Samra will be treated to meet the Jordanian Standards for discharge to wadis.

The process of investigating the potential options for using reclaimed water for irrigation of agriculture and/or forestry in the highlands has been iterative. The latest versions of each of these three options are presented here.

This document does not include the economic and financial analysis. This is presented in a separate Water Reuse Component Working paper (Shaner, 2000).

II. POTENTIAL OPTIONS

The four options for water reuse in the highlands, as shown in Figure II.1, are:

- Hashmeyeh, Zarqa and Ruseifeh project (Option HL#1);
- Highlands irrigation project (Option HL#2);
- Wadi Dhuleil and Khalidiyyeh irrigation project (Option HL#3); and
- Highlands irrigation distribution network (Option HL#4).

This report is concerned with options HL#2, #3 and #4. Option HL#1, which is concerned with industrial reuse, will be presented in a separate Water Reuse Component Working Paper.

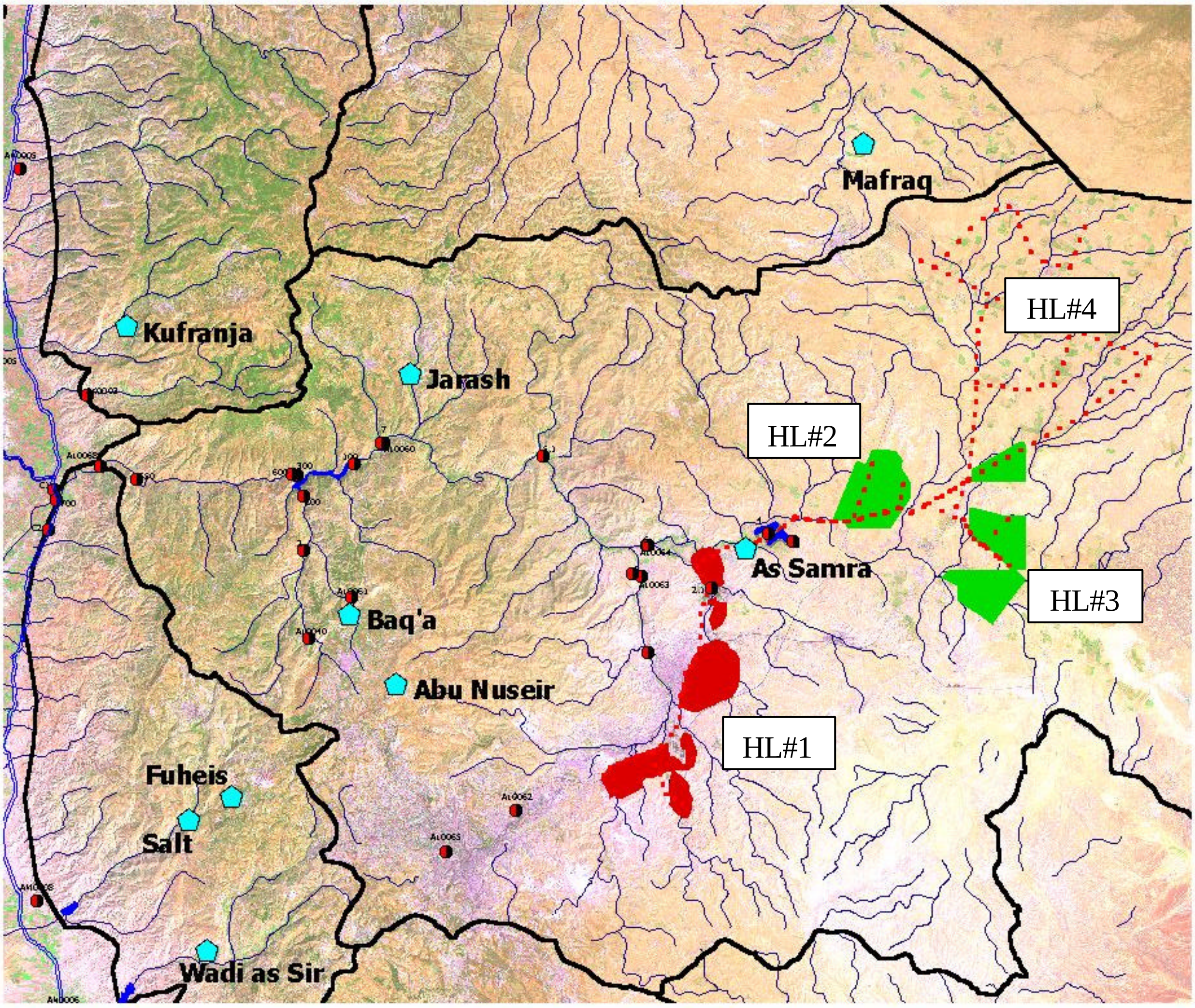

Figure II.1. Location of options for water reuse in the highlands of the Amman-Zarqa basin.

II.1. DESCRIPTION OF POTENTIAL OPTIONS

II.1.1. Highlands Irrigation Project (Option HL#2)

The HL #2 project, as shown in Figure II.2, is located approximately 5-km east of As Samra on either side of the Khaw to Marfaq highway, and could extend to at least 13,400 dunums (1,340-ha). The basic components of the conceptual design are a pumping station at As Samra, a conveyance pipeline and an open reservoir on the north edge of the project area.

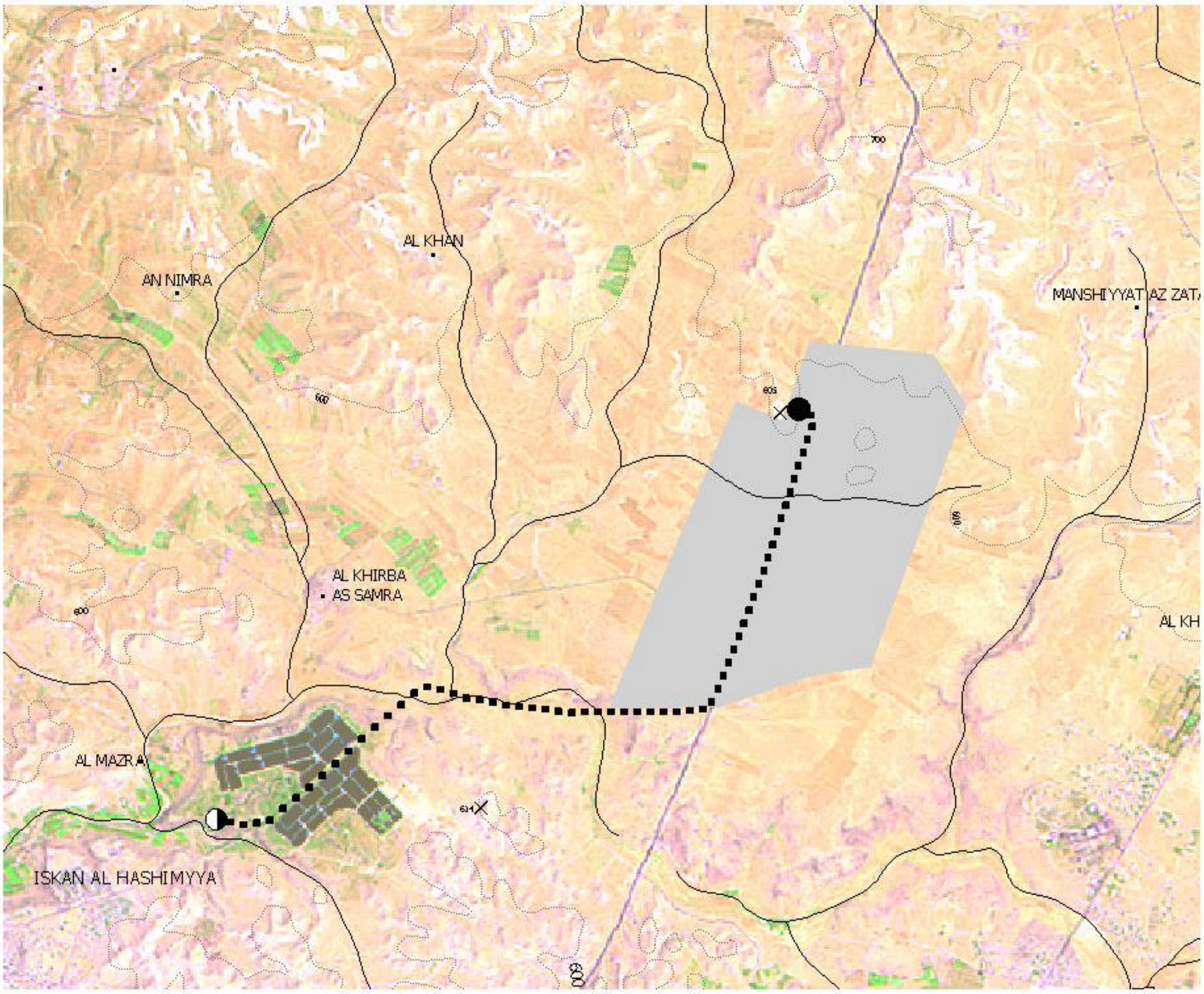

Figure II.2. Highlands irrigation project (Option HL#2).

II.1.2. Wadi Dhuleil and Khalidiyyeh irrigation project (Option HL#3)

The Dhuleil and Khalidiyyeh irrigation project (Option HL#3), as shown in Figure II.3, is located approximately 14-km east of As Samra. The most southerly of the three tracts on Figure II.3 is approximately 10,000-dunnums of land owned by the Water Authority of Jordan (WAJ) and includes the existing Dhuleil irrigation project. The present water source (groundwater) for the project is no longer viable. It is anticipated that this would be the first phase of a new irrigation project with future phases extending to the north, as indicated on Figure II.3. The basic components of the conceptual design for the first phase of the project are a pumping station at As Samra, a conveyance pipeline that follows the route of the existing oil pipeline and an open reservoir on the northern edge of the project area. The existing irrigation infrastructure within this tract will reduce the development costs, but betterment of this system will be required.

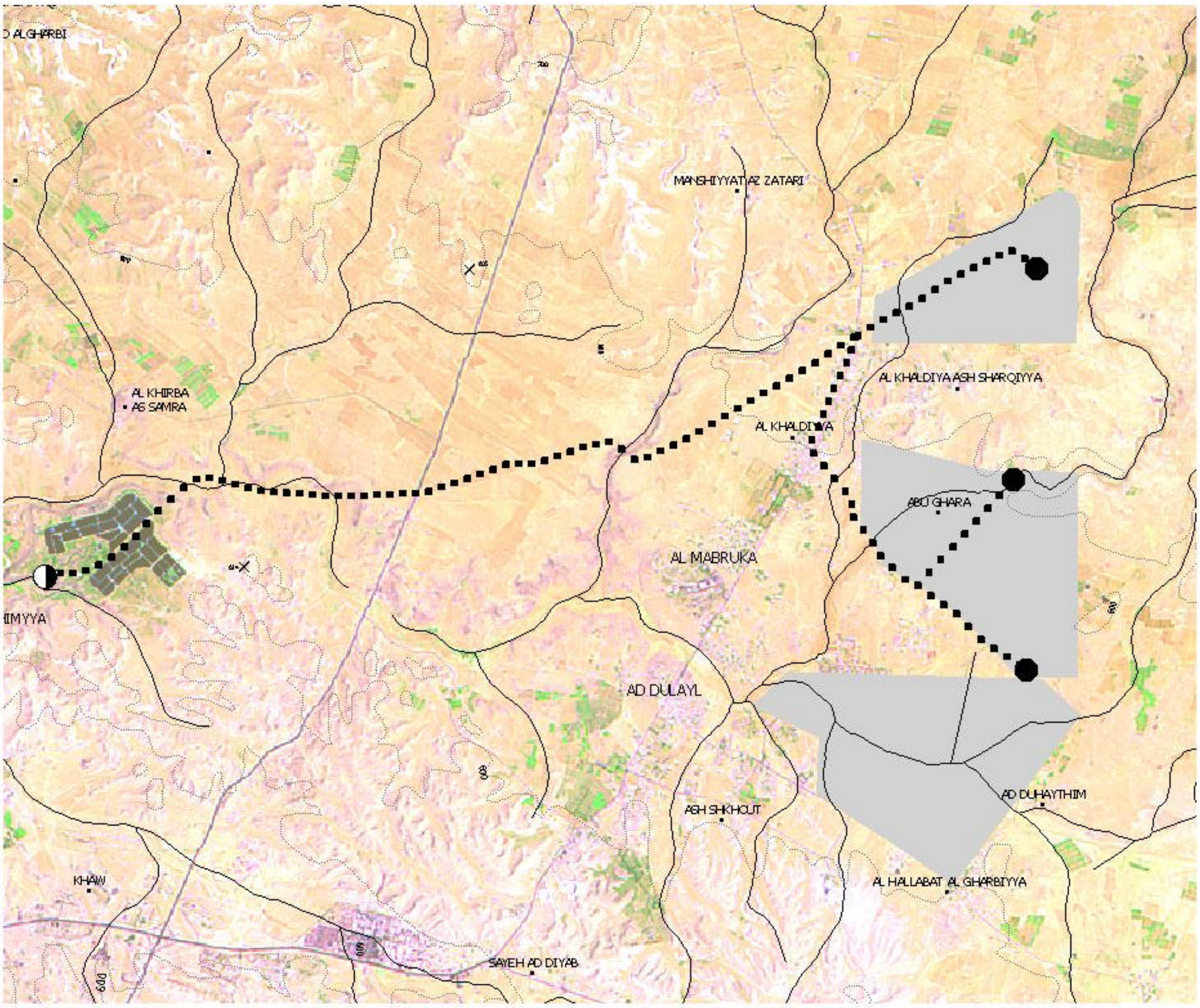

Figure II.3. Wadi Dhuleil and Khalidiyyeh irrigation project (Option HL#3)

II.1.3. Highlands irrigation distribution network (Option HL#4)

The highlands irrigation distribution network (Option HL#4) is located in the upper Northeastern area of the Zarqa drainage basin, and is intended to convey water to existing irrigated farms to exchange for groundwater supplies. Clearly this is a very expensive option, but may be viable of the value of the groundwater saved is high enough. The conceptual design of the project comprises two pump-stations, a network of large diameter pipes and at least three strategically placed reservoirs.

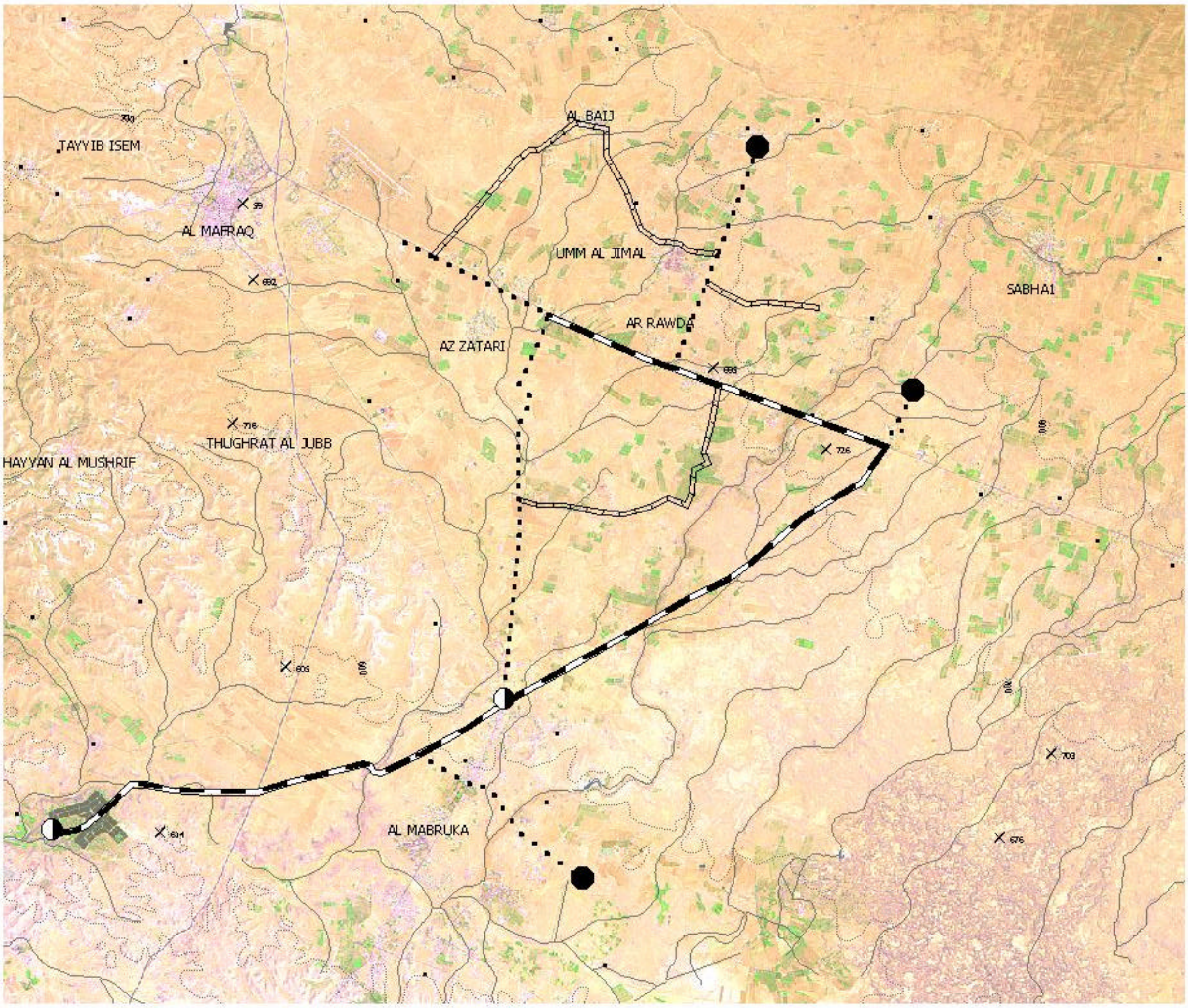

Figure II.4. Highlands irrigation distribution network (Option HL#4)

III. RECLAIMED WATER RESOURCES

The reclaimed water resources for the development of the highlands irrigation projects will be As Samra and, possibly, Wadi Zarqa wastewater treatment plants. The expected annual volumes, as developed in MWI/ARD (2000b), are shown in Table III.1. The results show that a further 50 MCM/annum is expected by the year 2010.

Table III.1. Projection of total effluent (MCM/annum) to be discharged from the As Samra and Wadi Zarqa WWTP

TREATMENT PLANT	2000	2005	2010	2015	2020	2025
Total As Samra-Zarqa effluent	61.3	68.9	110.2	127.1	145.2	165.9
Future available resource, in addition to current levels		7.6	48.7	65.8	83.9	104.6

It is assumed that the improvement of the As Samra plant will be completed in 2005, and the quality parameters will be as projected in ARD (2000b). Quality levels are expected to be in compliance with the respective Jordanian Standards, with a more stringent standard for the total nitrogen, which will be reduced to below 30-mg/l.

Further treatment of the reclaimed water is not anticipated, although disinfection will be advisable, and filtration at the field level will be required for the trickle application systems.

IV. LAND RESOURCES

This chapter presents a general overview of the land resources associated with the three potential options for irrigation of agricultural and/or forestry in the highlands of the Amman-Zarqa basin.

The soils in much of the portion of interest in the highlands, including all of the area associated with option HL#2, the areas associated with Phase II and III of option HL#3, and most of the area associated HL#4, have been classified by the Ministry of Agriculture (MoA, 1994). These maps do not cover the existing Wadi Dhuleil project area (HL#3, phase I) or a few of the farms furthest to the east in HL#4. These maps delineate and characterize the major soil units of the area. Although these provide useful information on the soils in the area, it is insufficient to determine the sustainability of these soils under irrigation.

In addition, as part of the investigations associated with the original Wadi Dhuleil project (Central Water Authority, 1965), a soil and landclass map was developed for part of the area of investigation. Figure IV.1 presents this map along with the footprints of HL#2 and HL#3. As can be seen, the area of investigation for the original Wadi Dhuleil project extended north and east to include all of Phase II and most of Phase III of option HL#3, and the majority of the area associated with HL#2. The soil and land classification system used in this investigation was that of the United States Department of the Interior, Bureau of Reclamation (USBR).

The USBR land classes are as follows:

Class 1 – “Arable” – Lands that are highly suitable for irrigated agriculture, which can produce and sustain relatively high yields of a wide range of climatically adapted crops. Soil and topographic conditions are such that no artificial farm drainage is required. These lands can be developed at a relatively low cost and have the capacity for a high rate of return.

Class 2 – “Arable” – Lands of moderate suitability for irrigated agriculture, with measurably lower production and able to support a relatively narrower range of crops. Morphological, topographical or chemical characteristics render these lands more expensive to develop and manage, and, generally, reduce the relative overall productivity.

Class 3 – “Arable” – Lands that are suitable for irrigated agriculture, but that have relatively extreme deficiencies in the characteristics of the soil, topography or drainage. These lands require higher levels of investment and present a higher degree of risk than class 1 or 2. However, carefully managed, these lands can produce an acceptable rate of return.

Class 4 – Limited “Arable” or Special Use – Lands are included in this class when special studies have shown them to be arable but suitable only for very restricted uses.

Class 5 – Non-Arable – Lands which have been determined to be non-arable under existing conditions but have the potential, following more detailed studies, to be upgraded to Arable.
Class 6 – Non-Arable – Lands which are not suitable for irrigated agriculture.

From the Central Water Authority (1965) map, none of the soils units in the investigation area were considered to be either class 1 or 4. The majority of the land was determined to be class 6 (non-irrigable), indicated in white in Figure IV.1. Note that phase II and III of HL#3 are, by USBR standards, not suitable for irrigated agriculture. The lands of the southern portion of phase I of HL#3, which is the existing Wadi Dhuleil project, and the northern portion of HL#2, are class 2 (irrigable). However, the southern, larger, portion of HL#2, which is generally shallower soil underlain by basalt, has been classified as class 5, and is indicated in pink in Figure IV.1. The constraint with the class 5 lands in this area is limited vertical drainage. This would be of particular concern with reclaimed water with elevated salt levels as good drainage would be essential to sustain irrigation. As explained by the Central Water Authority (1965), sustainable irrigation may be possible with an artificial drainage system, but this would involve substantial added expense.

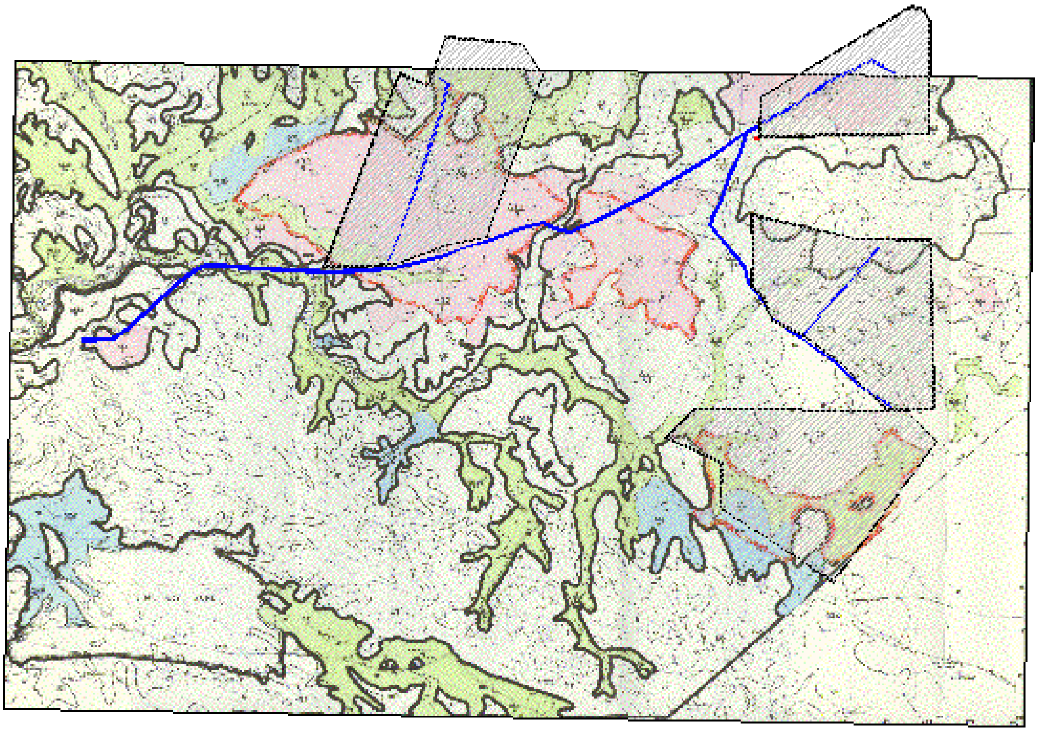

Figure IV.1. Soil and land classification map for the Wadi Dhuleil project (Central Water Authority, 1965)

The light blue areas in Figure IV.1 are class 3 lands. Although these are considered irrigable, they will require a higher degree of investment and/or management to generate good levels of returns. The specific constraint of the class 3 lands to the west of HL#2 is the dominance of gravels. The impediment of the class 3 land to the south of HL#3 (phase I) is that it is a mixture of lands which would be classified separately as class 2 and 6 (soils too shallow).

IV.1. Irrigable Land for HL#2a

Although further investment, in the form of an artificial drainage system, would allow sustainable irrigated agriculture to be practiced at HL#2, the availability of class 2 land nearby would provide a less expensive option. The soil map units identified as class 2 irrigable by the Central Water Authority (CWA, 1964) extended beyond the area investigated by the CWA. Extrapolation of the irrigable area to the limits of the soil map units identified considerable irrigable land resources. Figure IV.2 shows the irrigable lands and the lands that would require an artificial drainage system. Even excluding the areas that have been, to some extent, developed for either urban use or irrigated agriculture, there remains sufficient irrigable land to support an irrigated area of the magnitude being considered in this study.

Because of the limitations of the majority of the lands associated with the original footprint of HL#2, the general location of the option has been moved to the lands west and north of the original site. This site is identified as HL#2a. If necessary, further lands could be developed by expanding onto the irrigable lands to the north of the original footprint.

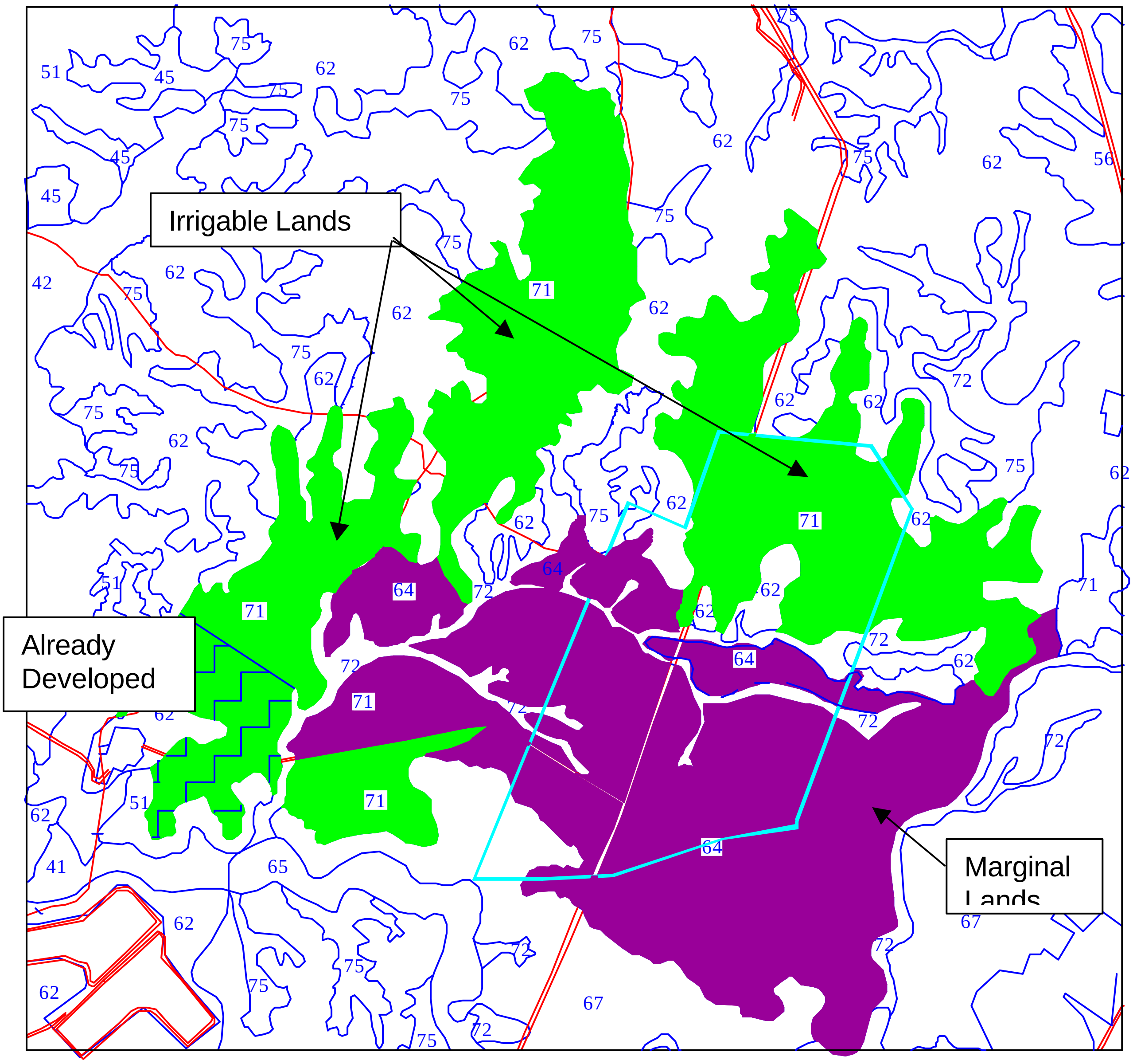

Figure IV.2. Irrigable lands within the general vicinity of HL#2.

IV.2. Irrigable Land for HL#3

As presented above, the areas being considered for Phase 2 and 3 of HL#3 are not suitable for irrigated agriculture. In fact, the only irrigable lands within the original footprints identified for this option are those of the original Wadi Dhuleil project (see Figure IV.1.).

IV.3. Irrigable Land for HL#4

This option would use reclaimed water on land that is presently irrigated with groundwater; therefore, the land has already been proven to be irrigable. The major soil map units in the area where these farms exist are 63, 64, 65, 66, 67 and 68, all of which are colluvium over basalt. The average depth of the soil over the basalt varies from 93-cm within unit 63 to 48-cm within unit 68. Further investigations would be required at specific sites to ensure the long-term sustainability of any particular soil unit. Unit 65, which represents wadi beds, and unit 68, which has many surface boulders, have obvious constraints.

V. CROPPING PATTERNS & WATER DEMAND

This chapter considers the cropping patterns that are likely to be the most practical for irrigation with reclaimed water in the highlands of the Amman-Zarqa drainage basin.

The selection of a cropping pattern lies with the producer, who has to rationalize many variables to ensure that an acceptable financial return is made considering the many risks involved. The supply of water for irrigation is one of the required inputs.

The two primary reasons for establishing a “design” cropping pattern are determination of the:

- economic and financial viability of irrigated agriculture under the specific conditions in the area;
- crop-water needs: thereby, defining the capacity of the pumping, conveyance, storage, distribution and application systems to meet those needs.

The four inter-related considerations in defining the crops that could be grown with reclaimed water in the highlands of the Amman-Zarqa basin are:

- viability of a crop in the area;
- present production of the crop under irrigation in the area;
- sensitivity of the crop to the elements in the reclaimed water; and
- compatibility of the crop with the present (and future) Jordanian Standards for irrigation with reclaimed water.

Where possible, irrigation systems should be designed so as to give the producer as much flexibility in determining cropping patterns. This allows the producer to respond to changes in the markets and, thereby, maximize returns. The detailed quantification of potential returns has not been undertaken, and will be incorporated in a later draft of this document as Chapter IX (Economic and Financial Analysis).

This chapter presents an overview of the irrigated crops that can be grown in the study area and the crops that are presently produced. This comprehensive list of crops is reviewed with respect to the compliance of specific crops with the Jordanian Standards for water reuse.

V.1. Irrigated Cropping Patterns and Crop Groups in the Study Area

A comprehensive list, or group, of crops grown in each of the agro-climatic zones of Jordan is included in the Ministry of Water and Irrigation database (MWI, 2000). As shown in Figure V.1, the options being considered here are all within agro-climatic zone 10. The crop group for this zone is summarized in Table V.1.

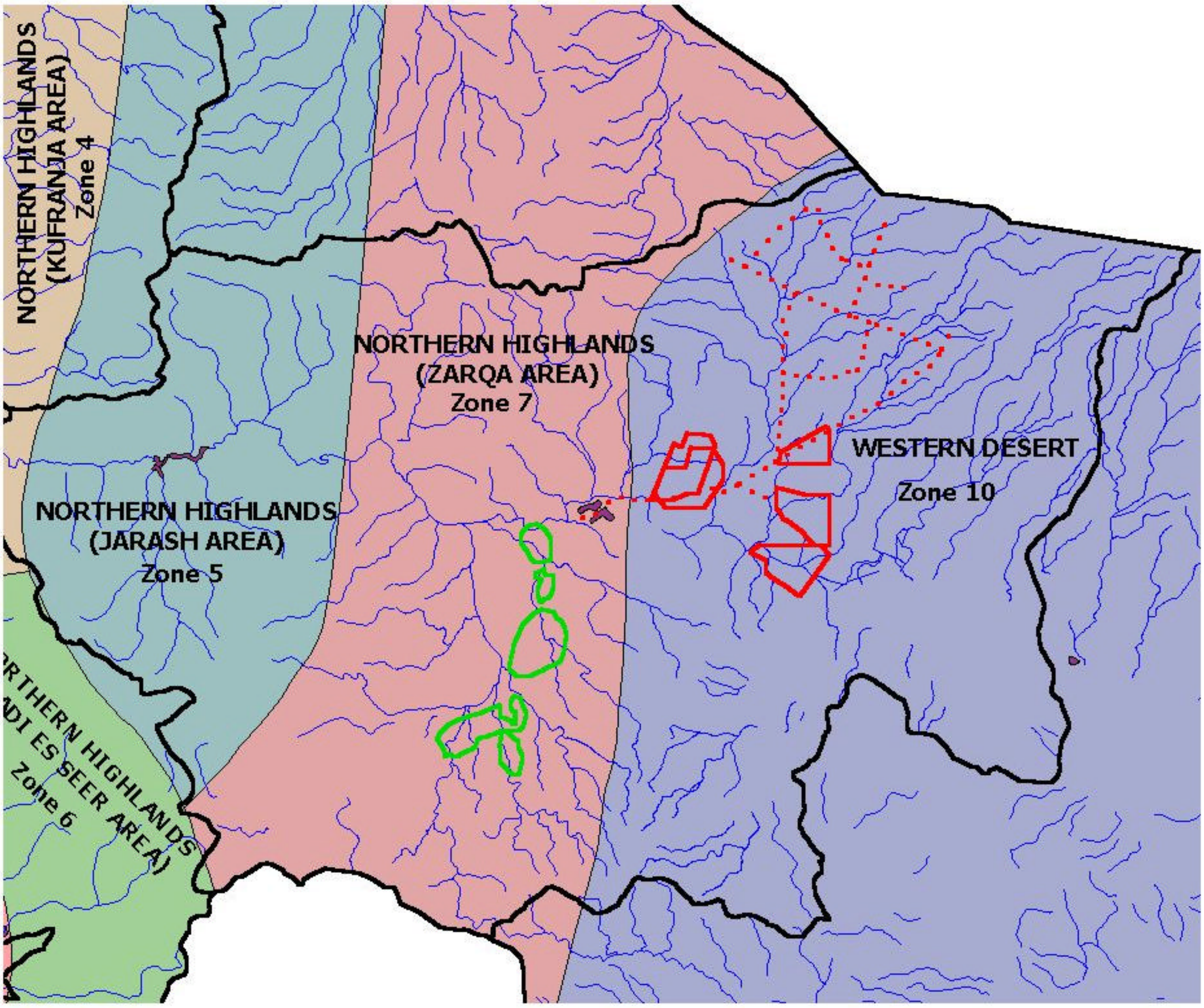

Figure V.1. Agro-climatic zones in the Amman-Zarqa basin.

Table V.1. Summary of crop group (MWI, 2000) for agro-climate zone #10

CROP	CROP	CROP
Autumn Fruit	Garlic	Other vegetables
Barley	Grapes	Peas
Broad Beans	Green Beans	Pepper
Carrot	J_Malok	Potato
Citrus	Late Fruit	Radish
Crucifers	Lettuce	Spinach
Cucumber	Melons	Squash
Dates	Okra	Tomato
Early Fruit	Olives	Turnip
Egg Plant	Onion	Wheat

The Rapid Appraisal, conducted as part of the Groundwater Component of this project, itemized the crops grown on the farms in the area. Of these, peaches, apples, cauliflower, alfalfa and "other deciduous" are not specifically included in the crop group. Peaches and apples are more than likely included in the autumn fruit, and cauliflower under "other vegetables". Field observations in the area near HL#2 show that cauliflower is a significant crop.

In addition to the above crops, commercial forest, which was one of the original concepts when exploring water reuse in the highlands, has been added to this list. Furthermore, flowers are also considered a potential crop that could produce a high rate of return, although experience to date in the area is limited. Ornamental plants and flowers are grown in Wadi Zarqa.

Table V.2. Comprehensive list of potential crops

CROP	CROP	CROP
Alfalfa	Flower	Other vegetables
Apples	Forest	Peaches
Autumn Fruit	Garlic	Peas
Barley	Grapes	Pepper
Broad Beans	Green Beans	Potato
Carrot	J_Malok	Radish
Cauliflower	Late Fruit	Spinach
Citrus	Lettuce	Squash
Crucifers	Melons	Tomato
Cucumber	Okra	Turnip
Dates	Olives	Wheat
Early Fruit	Onion	
Egg Plant		

V.2. Compliance with the Jordanian Standards

The present Jordanian Standards state that crops to be grown raw should not be irrigated with reclaimed water. If this were to be interpreted to the letter then crops such as peaches, where, with careful management, the water does not come in contact with the edible portion of the crop, would be excluded from irrigation with reclaimed water. Similarly, crops where the edible portion would have to be peeled, such as water melon, would also be excluded.

As detailed in Appendix B, the cost of developing reclaimed water as a source for irrigation, and the need to prevent loss of the reclaimed water - and associated fertilizers and pesticides - to the groundwater, dictates that the irrigation application mechanism should be some form of pressurized system. However, sprinklers are not suitable for reclaimed water, because of the health risk of the aerosol generated. Considering this, some form of drip or trickle system is the best, if not the only, option for using reclaimed water in the highlands of the Amman-Zarqa. The limitations are that certain crops, particularly those broadcast, such as barley, wheat and alfalfa cannot in practice be effectively irrigated with drip or trickle technology. Certain variations of the overall system, such as sub-surface irrigation, mini-sprinklers and bubblers, need to be considered to allow a wider variety of crops and to minimize the need for filtration.

Considering the above, Table V.3 presents list of those crops that comply, those that may comply and those that clearly do not comply. Those crops that may comply will be considered in more detail as part of the review of the standards. It is conceivable that revised standards would make the cropping pattern even more restrictive, but, as can be seen, the list of crops that clearly comply at this time is already restricted.

Table V.3. Comprehensive list of potential crops

	COMPLIANCE	
YES	**MAYBE**	**NO**
Alfalfa[1]	Apples	J_Malok
Forest	Grapes	Lettuce
Flowers	Green Beans	Pepper
Barley[1]	Peaches	Cauliflower
Broad Beans	Melons	Carrot
Garlic	Okra	Radish
Olives	Cucumber	Spinach
Citrus	Turnip	Tomato
Dates	Peas	
Potato		
Egg Plant		
Onion		
Squash		
Wheat[1]		

[1]Crops not suitable for irrigation with drip or trickle.

V.3. Sensitivity to Quality of Reclaimed Water

The sensitivity of crops to the constituents found in As Samra effluent is discussed in detail in Grattan (2000). Of particular note is the sensitivity of citrus, grapes, stone fruit, beans and onions to salt and/or chlorides. All of these crops are presently grown with As Samra effluent either in the Jordan Valley or Wadi Zarqa, but yields are lower than potential or, in the case of tree crops, the life span of the tree is restricted.

V.4. Water Demands

To specify the design requirements of the water pumping, conveyance, storage, distribution and applications system, the expected crop water demands need to be determined. As discussed above, the system should provide sufficient flexibility to allow for significant changes in cropping patterns so as to allow the producer to respond to the realities of the markets. The system also needs to deliver sufficient water to leach salts from the root-zone.

V.4.1. Crop-Water Demand

The two parameters of interest with respect to the crop water demands are the peak water demand, and the overall seasonal water demand.

Various mixes of shallow (eg. onions), medium (eg. wheat, alfalfa) and deep rooting (eg. olives, conifers) crops were considered as potential cropping patterns. The crop water requirements for each crop, and various cropping patterns was generated using CROPWAT version 4.2. (FAO, 1998), using climate data from the Wadi Dhuleil station, and rooting depth and adjusted crop coefficients from the Ministry database (MWI, 2000).

The silt to silty loam soils of the area were taken to be of medium total available moisture (140-mm/m), and the efficiencies of the conveyance, distribution and application systems were assumed to be 98, 98 and 80 percent respectively, with drip or trickle application technologies and pressurized pipe for the entire system. For surface application systems, the application efficiency was taken as 45 percent.

The net and gross peak daily irrigation cropping patterns for the individual crops, and three different cropping patterns, are shown in Table V.4. The application effeciency varies between that for trickle (80 %) and that for surface (45%). As discussed above, the application system will be trickle. Based on this, the design peak gross irrigation requirement was taken as 1.1-lps/ha.

Table V.4. Theoretical peak irrigation requirements for crops and cropping patterns.

	Onions	Wheat	Alfalfa	Olives	Forest		IRRIGATION REQUIREMENT	
						Ea	Net (mm)	Gross (lps/ha)
Onions	100 %					80 %	6.4	0.6
Wheat		100 %				45 %	6.9	1.8
Alfalfa			100 %			45 %	6.4	1.6
Olives				100 %		80 %	6.4	0.93
Forest					100 %	80 %	6.4	0.93
Pattern I		30 %	40 %		30 %	65 %	6.3	1.12
Pattern II	30 %		30 %	40 %		65 %	3.8	0.7
Pattern III		30 %	30 %	40 %		65 %	4.4	0.8

Based on pattern II above, that is 30, 30 and 40 percent of shallow, medium and deep rooting crops respectively, the expected annual water requirement will be 890-mm, or 8900-m^3/ha distributed as shown in Figure V.2.

V.4.2. Leaching Requirement

In addition to the crop-water needs, sustainability of irrigation under these conditions will require considerable leaching. The leaching requirement can be determined from:

$$\frac{Dp}{Di} = \frac{Ci}{Cp}$$

Where Dp = depth of leaching required
Di = depth of irrigation (annual)
Cp = concentration of drainage water
Ci = concentration of irrigation water

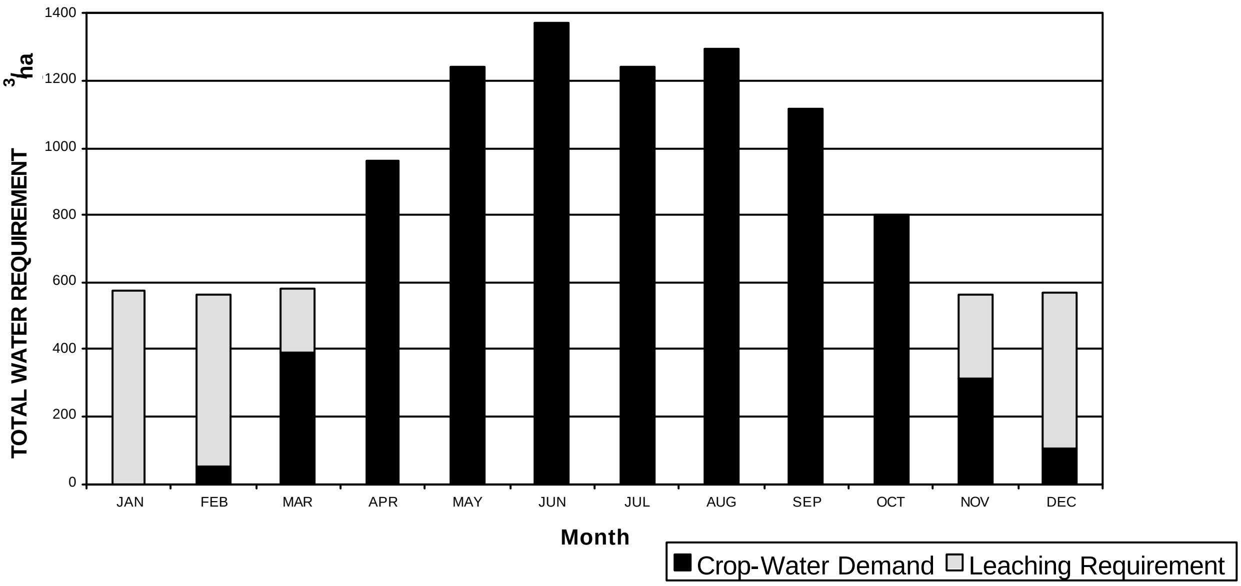

Figure V.2. Crop-water and leaching requirements for each month

The water supply is expected to have a salt concentration of 1,200-mg/l, and, from above, the total water consumed per year is around 890-mm. Assuming a concentration of the drainage water of 5,300-mg/l, the leaching requirement is approximately 200-mm. This leaching requirement does not account for salts added to the rootzone by fertilizers nor the potential natural leaching by rainfall.

It is assumed that the leaching will be done in months when the crop-water demands are lower than peak. Figure V.2 shows the effect of spreading the leaching requirement over the low-water demand months, and demonstrates that there is some remaining capacity should field monitoring prove that further leaching is required. The annual water requirement is, therefore, 1,190-mm, or 11,900-m^3/ha.

V.I. HIGHLANDS IRRIGATION PROJECT (OPTION HL#2a)

VI.1. Land Resources

As detailed in Chapter IV, the area originally location for option HL#2 (after Harza, 1997) was found to be dominated by soils that would not be suitable for long-term sustainability of irrigated agriculture (USBR class 5). The particular constraint is the relatively shallow soil underlain by basalt, which would limit downward drainage. Drainage is an absolute requirement with reclaimed water, which will have relatively high salinity levels. This constraint could be overcome with the installation of an artificial drainage system. However, the additional expense will further limit the financial viability of this option. Because of the issue presented above, the option was relocated to the west onto lands that should prove more sustainable for irrigated agriculture, as delineated in Figure IV.2. This revised option is identified as HL#2a.

To minimize pumping costs, it is prudent to develop the most low-lying irrigable lands. The proposed area extends northwards from the settlement of As Samra, along the rail-line. The gross area of the project extends to approximately 10.2 - km^2, although further lands could be developed further to the north and east if required. The net irrigated area of the delineated, accounting for the land taken up by roads and other infrastructure, will be approximately 90 percent of the gross, or 9.2 - km^2 (9,200 – dunums).

VI.2. Water Requirements

From Chapter V, the total annual water supply, which includes the crop-water needs, the leaching requirement and the expected losses, is 1340-mm per annum. For this option the volume required per annum is 12.33 M-m^3. The expected peak rate of delivery is 1178-lps.

VI.3. Conceptual Design

The main system infrastructure would consist of a pumping station at the outlet of the wastewater treatment plant and a conveyance pipeline serving eight irrigation blocks, as shown in Figure VI.1. Each irrigation block will have a reservoir and minor pumping plant serving a distribution network. Water would be delivered within each block either directly from the conveyance line or from the reservoir. The application systems will be trickle. Filtration facilities would be provided either at the block level or at riser supplying the trickle system. Details of the conceptual design are presented in Appendix A.

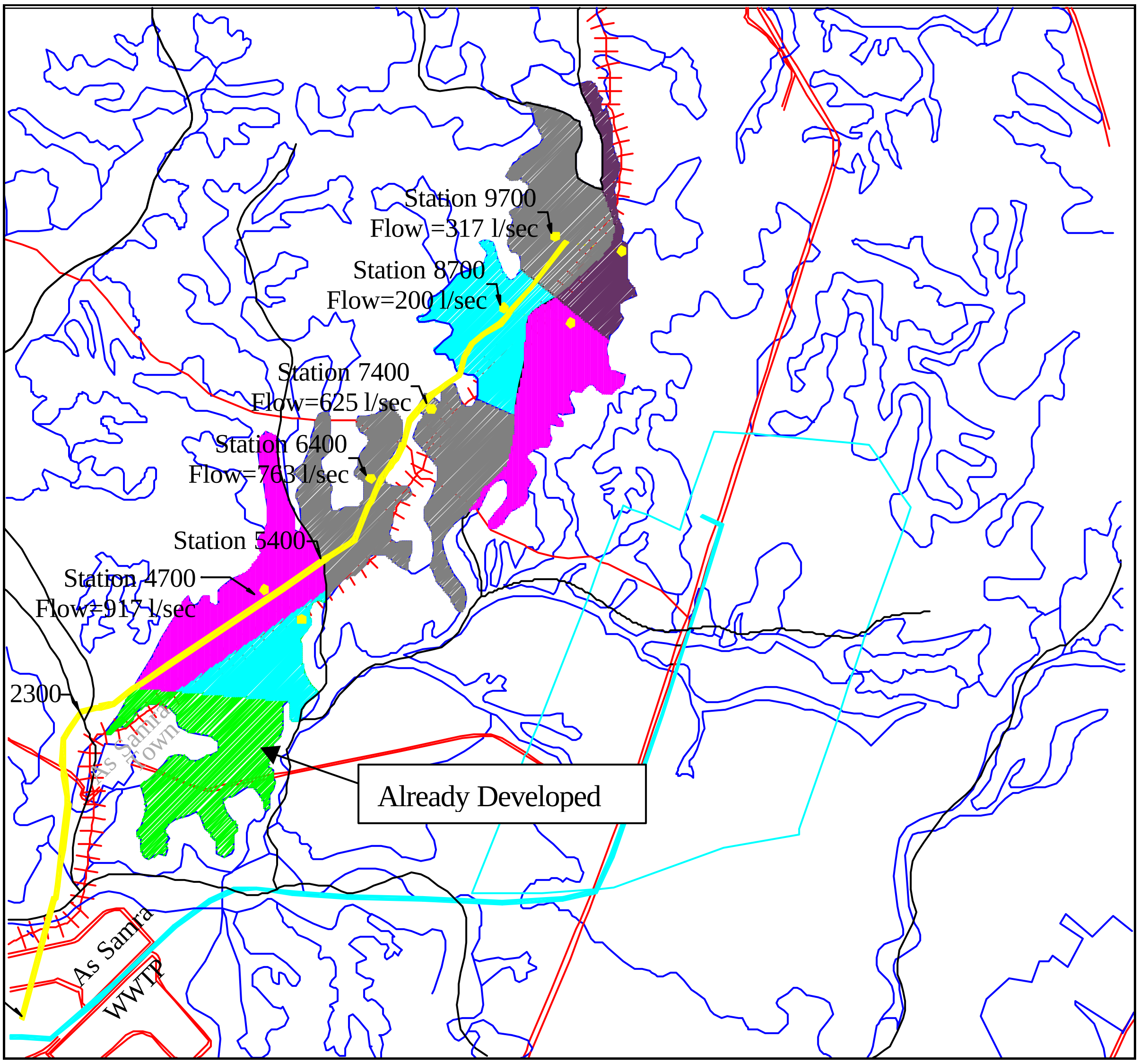

Figure VI.1. Layout of HL#2 irrigation project

VI.3.1. Conveyance & Pumping

With a design peak discharge of 1.12– lps/ha and a maximum velocity for the conveyance pipeline of 1.5 – m/s, the 9700-m pipe will require diameters as shown in Table VI.1. The total dynamic head for the conveyance line is 112-m. Further details of the hydraulic calculations are provided in Table A.1. (Appendix A).

Table VI.1. Summary of conveyance pipeline dimensions for HL#2a.

LENGTH (m)	DIAMETER (mm)
2300-m	800-mm
4100-m	700-mm
1000-m	600-mm
1300-m	500-mm
1000-m	300-mm

VI.3.2. Storage

As discussed above, each of the eight irrigation blocks would have an above-ground reservoir capable of storing the peak daily demand for the block. The largest block, as defined in Figure VI.1, is 1.6-km^2, which would have a peak daily demand of 15,552-m^3. The reservoir storage capacity was, therefore, set at 18,000-m^3. That is, 5-m depth and 60-m square. For the conceptual design, this was used as the reservoir dimensions for each of the blocks. Details of the preliminary design can be found in Appendix A.

VI.3.3. Distribution System

Each block within the project area has an irregular shape. However, at this stage, the basic layout for the distribution system is based on a square kilometer. The basic layout for the network is shown in Figure VI.2. The distribution system would be supplied from the reservoir by means of a pumping system. The pumping and distribution systems have been sized to allow a peak supply rate of 1.88-lps/ha. The pressure developed at the pumping plant will be sufficient to operate the application system without further pumping (TDH = 70-m).

VI.3.4. Application System

As discussed in Chapter V, the necessity to conserve water in general and the specific needs of irrigating with reclaimed water dictate that neither surface nor sprinkler irrigation systems are suitable for this situation. By default, drip or trickle irrigation is the recommended technique for application in this project.

The specific design of the application system will depend on the layout of the area to be irrigated and the crops to be grown. However, the basic layout, at least with respect to determining the costs, will be either that for row crops or for tree crops.

VI.4. Cost Estimates

The estimated capital cost for the project, as described above, is 19.1 M-JD. The estimated annual cost is 2.60 M-JD, which is about 210-fils per cubic meter, not including the on-farm inputs. Details of the cost estimates can be found in Appendix C.

VI.5. Further Considerations

The remaining major concern, other than the cost, of this option would be the potential for contamination of the groundwater with the reclaimed water, and the salts and agricultural residuals that would be leached from the soil profile.

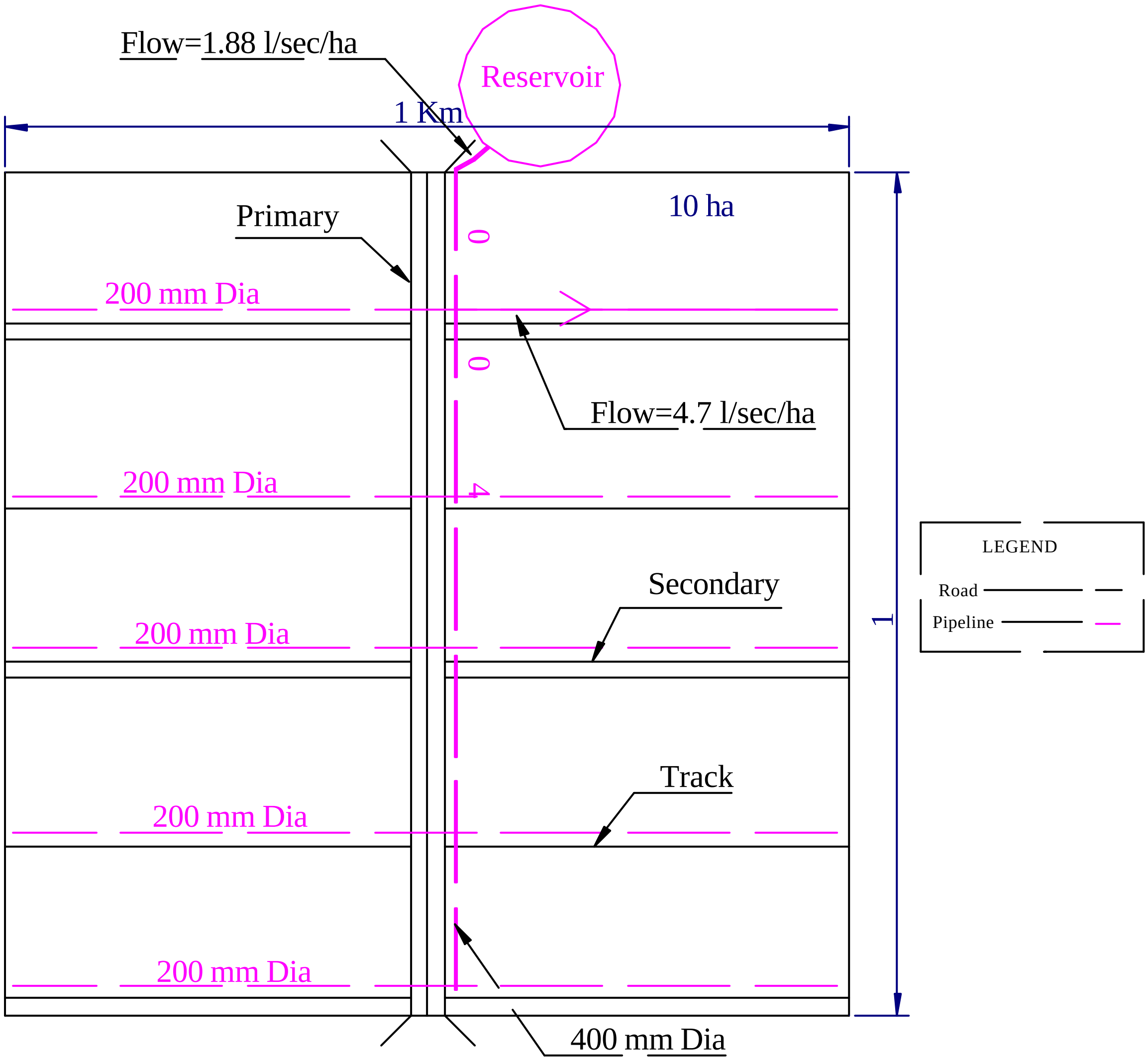

Figure VI.2. Basic distribution system layout.

VII. WADI DHULEIL & KHALIDIYYEH IRRIGATION PROJECT (OPTION HL#3)

This option would provide reclaimed water to existing irrigated lands and, possibly, new lands in the Wadi Dhuleil area.

VII.1. Land Resources

From Chapter IV, the irrigable land available within the boundaries for HL#3 is restricted to that within the original Wadi Dhuleil project (CWA, 1964). The remaining area within HL#3 phase I, and all of HL#3 phase II and phase III are not suitable for irrigated agriculture.

The gross area within the original Wadi Dhuleil project is 8,000 dunums (800-ha), all of which is considered irrigable (USBR class 2). Considering the existing irrigation infrastructure and the roads, the net irrigable area will be around 90 percent of this, or 7,200-dunums (720-ha). From 1994 satellite imagery, the gross area presently irrigated extends to approximately 4,600-dunums.

VII.2. Water Demand

The basic concept with providing reclaimed water for Wadi Dhuleil would be to replace the ground water as the source and expand the irrigated area to the boundaries of the project, which are defined by the irrigable lands. From 1995 through 1999 the average annual production from the three wells has been approximately 2.5 M-m^3, which is half of what would be expected to fully irrigate 4,600 dunums of land in this area. The salinity levels, as shown in Table VII.1, show that this sources places severe restrictions on the crops which could be grown in the area. This confirms the feedback received from farmers on the project.

Table VII.1. Summary of salinity records for the Wadi Dhuleil wells (MWI, 2000)

WELL	INSTALLED		SALINITY	
	DATE	SALINITY	1991	1995
AL 1030	1966	314-mg/l	1770-mg/l	3410-mg/l
AL 1037	1972	448-mg/l	2560-mg/l	1560-mg/l
AL 1748	1966	1780-mg/l	NR	NR

NR: No Record

From Chapter V, the total water requirements for an improved project that extends to the area available, and uses a fully piped system would be 9.6 M-m^3.

VII.3. Conceptual Design

The existing irrigation infrastructure at Wadi Dhuleil comprise three wells, as described above, a manifold pipeline that conveys the water to the head of the distribution system and the storage reservoir, a storage reservoir of around 16,000-m^3, a distribution system of concrete lined canals, and application by small to medium sized basins.

The new system would comprise of a pumping station at the outlet of the wastewater treatment plant and a conveyance pipeline serving seven irrigation blocks, as shown in Figure VII.1. Each irrigation block would have a reservoir and minor pumping plant serving a distribution network. The existing reservoir would serve as a reservoir for one of the blocks. Water would be delivered within each block either directly from the conveyance line or from the relevant reservoir. The application systems will be trickle. Filtration facilities would be provided either at the block level or at the riser supplying the trickle system.

VII.3.1. Conveyance & Pumping

Using the same assumptions as in HL#2a (see VI.3.1. for details), 30,300-m pipe will require diameters as shown in Table VII.1. The total dynamic head for the conveyance line is 112-m. Further details of the hydraulic calculations are provided in Table A.1. (Appendix A).

Table VII.1. Summary of conveyance pipeline dimensions for HL#3.

LENGTH (m)	**DIAMETER (mm)**
11,200-m	1000-mm
13,200-m	900-mm
5,900-m	800-mm

VII.3.2. Storage

There are seven reservoirs required for HL#3. Apart from the existing one, the conceptual design for the remaining six was as those for HL#2a (see VI.3.2. for details).

VII.3.3. Distribution System

As for HL#2a (see VI.3.3. for details), the distribution system was developed for a square kilometer using the same hydraulic considerations. However, the main pipes were routed along the same right-way as the existing canals.

VII.3.4. Application System

As for HL#2a (see VI.3.4. for details), the recommended application system for this option is drip or trickle.

VII.4. Cost Estimate

The estimated capital cost for the project, as described above, is 28.2 M-JD. The estimated annual cost is 3.65 M-JD, which is about 380-fils per cubic meter, not including the on-farm inputs. Details of the cost estimates can be found in Appendix C.

VII.5. Further Considerations

The remaining major concern, other than the cost, of this option would be the potential for contamination of the groundwater with the reclaimed water, and the salts and agricultural residuals that would be leached from the soil profile.

VIII. HIGHLANDS IRRIGATION DISTRIBUTION NETWORK (OPTION HL#4)

VIII.1. Land Resources

With the information that is available, which is limited relative to that available for the other options, and the fact that irrigated agriculture is already being practiced on farms in question, it is safe to assume that the sustainability of irrigation on the soils is not an issue.

VIII.2. Water Requirements

According to 1998 data, the consumption of groundwater for irrigation in the Zatari and North Badia areas totals less than 29 M-m^3/annum (MWI, 2000). To develop a project of around 10 M-m^3/annum would require that over 35 percent of the irrigated land be serviced by the delivery system and that the farmers convert to using reclaimed water. Based on the same ratio of annual volume to peak daily volume, the conveyance system would have to be able to deliver 955-lps.

VIII.3. Conceptual Design

The main system infrastructure (see Figure VIII.1) would consist of two pumping stations, one at the outlet of the wastewater treatment plant and one part the way up the conveyance line. This would deliver to either one (as considered here) or multiple reservoirs. Distribution networks would deliver water to existing individual farms.

VIII.3.1. Conveyance & Pumping

As presented above, the peak would be 955-lps. The total dynamic head to reach the reservoir is 300-m. The pipeline would be 40-km in length and 1,200-mm in diameter.

Table VIII.1. Summary of conveyance pipeline dimensions for HL#4.

LENGTH (m)	**DIAMETER (mm)**
40,000-m	1,200-mm

VIII.3.2. Storage

The storage reservoir was sized to store one day of peak water use. Practically more than one reservoir could be constructed, but, as presented below, the costs do not justify detailed investigations.

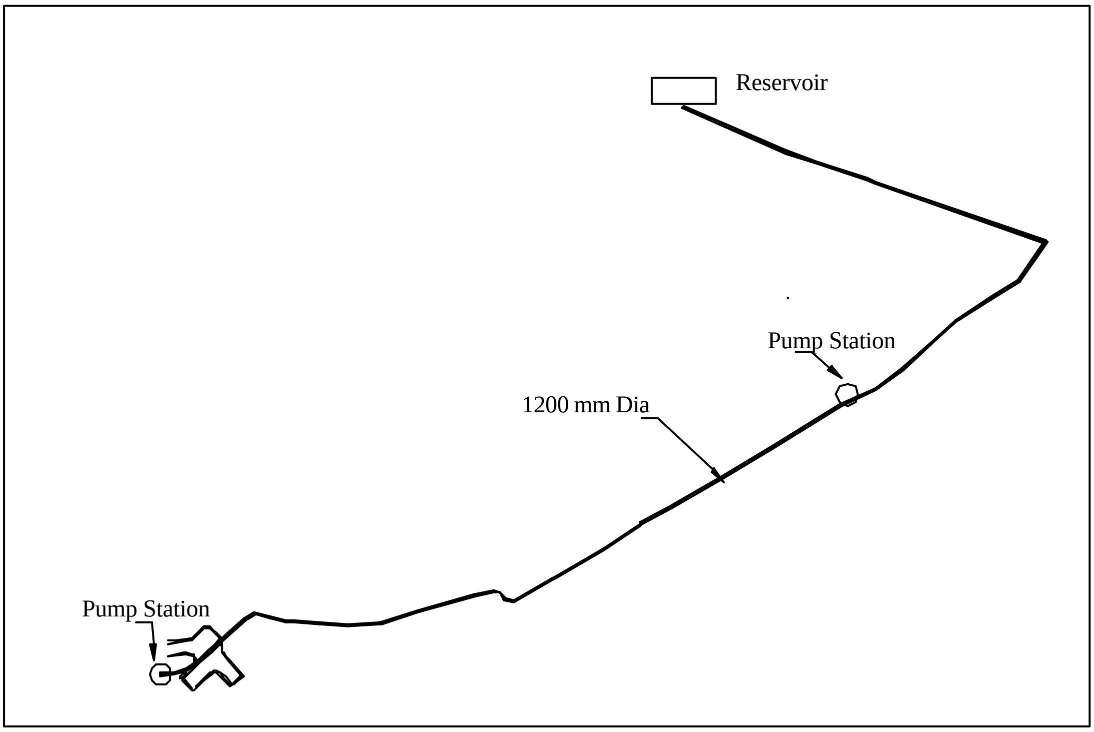

Figure VIII.1. Layout of HL#4 pumping, conveyance and storage system

VIII.3.3. Distribution System

The distribution system was not been designed for this option as the main system is already prohibitively expensive.

VIII.3.4. Application System

Many of the farms already have drip or trickle systems. But each would need to be specified (see VI.3.4) to meet the needs of using reclaimed water.

VIII.4. Cost Estimate

The estimated capital cost for the main components of this option, which are the pumping stations, conveyance pipeline and storage facilities, is estimated to be 44.3 M-JD. Annual costs for the same main system will be around 5.7 M-JD, or about 570-fils per cubic meter. This does not include the extensive distribution system and upgrades to on-farm application systems. Details of the cost estimates can be found in Appendix C.

VIII.5. Further Considerations

The deep percolation of the reclaimed water beyond the rootzone, as part of the leaching process, is a pre-requisite for sustainable irrigated agriculture. However, this leachate, which comprise the reclaimed water, the concentrated salts from the rootzone and any residual fertilizers or pesticides used in agriculture production, are potential contaminants for the groundwater.

The technical success of this option would hinge on the conversion of farms from groundwater to reclaimed water. Although most of the farmers interviewed during the Rapid Appraisal for the Groundwater component expressed an interest in using such a resource, it will be difficult to ensure that reclaimed water is not used to expand the irrigated area.

IX. COMPARISON OF OPTIONS

This chapter considers the three irrigation based water reuse options examined in this study, and their relative merit. The final economic analysis will be completed soon. This will, among other things, consider the economic merit of replacing the present use of groundwater resources with the reclaimed water at HL#3 and HL#4.

It was anticipated from the outset that the options would be relatively expensive, with the most expensive being furthest and highest from the treatment plant. However, because of limitations placed on the scale of the options due to land resources (HL#2 and HL#3), and the volume of water presently used (HL#4), the unit cost for developing and operating each are even higher. From the investigation and analysis to date, the key characteristics for each option, in terms of water requirements and costs, are presented in Table IX.1.

Table IX.1. Key characteristics of highlands irrigation reuse options

	Gross Irrigable Area (dunums)	Total Water Requirement (m^3)	COSTS Total ** Capital (JD)	Per m^3 (fils/m^3)	Per Dunum * (JD/dunum)	Per Ha ($US/ha)
HL#2a	10,200	12,330,000	19,100,000	210	1,873	26,216
HL#3	8,000	9,600,000	28,200,000	380	3,525	49,350
HL#4		10,000,000	44,300,000	570		

*based on gross irrigable area

**excluding filtration , disinfection and non -irrigation on farm inputs

As previously mentioned, all of these options are expensive. For HL#3 and HL#4, some of the costs may be offset by the potential savings in ground water. However, the present 2.5 M-m^3 of groundwater used at HL#3 is already saline (2500-3000-mg/l). The costs for HL#4 do not include the distribution system, which will prove expensive.

Prior to the completion of the economic analysis, any conclusions are tentative, but the above projects, and the general concept of pumping reclaimed water into the highlands for agricultural reuse, does not appear viable if depending on agricultural returns only.

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GLOSSARY OF TERMS

Cropped area: The cumulative area of crops planted over a year.

Cropping intensity: Cropped area / irrigated area

Direct Water Reuse: The beneficial use of reclaimed water that has been transported from the treatment plant to the point of use directly through pipes or in lined channels, without an intervening discharge to a natural water body, such as a stream of pond.

Domestic Wastewater: Wastewater generated in residential and commercial activities, possibly also including minor amounts of industrial wastewater subjected to pre-treatment meeting the requirements of connection to the sewer network issued by the Department of Meteorology and Standards.

Effluent: Flow discharged at the end of a treatment process or a treatment train, which may be suitable for some uses, depending on the level of remaining pollutants.

Food Crops: Any crops intended for human consumption.

Guidelines: Semi-official rules and limits for long-term sustainability of water activities in agricultural, industrial or urban sectors.

Indirect Water Reuse: The use of effluent from a wastewater treatment plant after it has been discharged to a natural water body, such as a stream, pond, or reservoir.

Irrigable area: The area of land that can sustainably be used for irrigation.

Irrigated area: The area of land that is under irrigation.

Recycled Water: Water created as a result of treatment and disinfection of wastewater, and deemed safe for specific, intended uses (defined above). Recycled water is a water resource, with tremendous beneficial usefulness, the only limitations being dependent upon level of treatment, salt content and other characteristics that might restrict it to certain uses.

Reclaimed Water: Synonymous with "recycled water," and usually used interchangeably. Strictly speaking, "reclaimed" water originates at a central water reclamation facility, whereas "recycled" water originates onsite. This is especially true at an industrial site recycling its own water over and over again, for example in a cooling tower.

Regulations: Legally adopted, enforceable rules and limits for water reclamation activities, with measured penalties provided for violations.

Standards: Limits on specific parameters, set for the purpose of protecting the public health, or the environment. Standards are usually incorporated in regulations. Sometimes "standards" are used synonymously with "regulations".

Unplanned Reuse: Withdrawal by gravity or pumping from wadis where a major portion of the flow is effluent from an upstream wastewater treatment plant. This is an unauthorized use of wastewater, even if at the point of discharge, effluent quality meets the standards in effect.

Unrestricted Use: Use of pathogen-free water for all non-potable uses, including irrigation of food crops consumed without further processing. The restriction on potable use still applies, unless treatment includes membrane filtration and fail-safe provisions against survival of microorganisms and trace organic compounds.

Use Area: Any area where reclaimed water is used, with defined boundaries.

Wastewater: Polluted and contaminated sewage, resulting from residential, and industrial uses of water and carrying waste products, including organic materials, inorganic compounds, and various microorganisms. Wastewater, *per se*, is not a water resource for any beneficial uses, unless treated appropriately and converted to "recycled water".

Wastewater Reuse: Unregulated (illicit) use of wastewater or inadequately treated wastewater effluent for irrigation of crops or for any other uses.

Water: All usable water, including surface runoff, groundwater, brackish, and recycled water, but excluding contaminated, saline, and raw wastewaters, which are unsuitable for beneficial use.

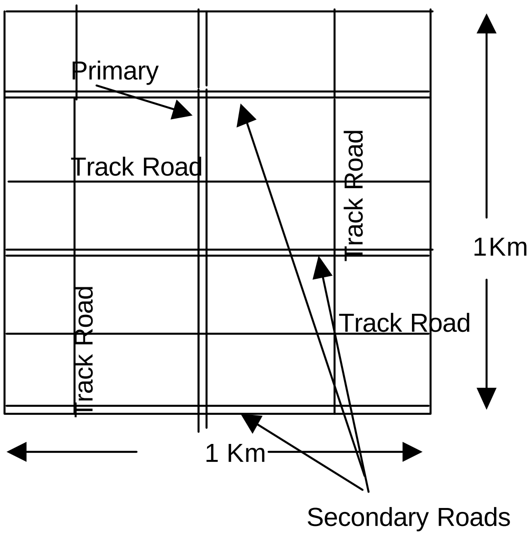
Water Reclamation: The process of salvaging usable water from wastewater by mechanical treatment (physical, chemical and biological) and disinfection, salt removal, or natural processes.

Water Recycling: Synonymous with "water reuse." This term is used in some regions exclusively in reference to all water reclamation and reuse activities, because of the positive public image of "recycling" as an environmentally good deed.

Water Reuse: The intentional, planned reclamation of water from wastewater and its conveyance and distribution to agricultural, industrial, and other sites, where it can be put to beneficial use. The terminology "wastewater reuse" is avoided in this document to prevent confusion with the unplanned, unauthorized uses of inadequately treated waste and its unwholesome consequences.

APPENDIX A
DESIGN CALCULATIONS FOR HL#2a

PROJECT AREA (Distribution system, roads and surface drainage



Pipes mm (Dia)	Unit Cost (JD / m)
400	55
200	30

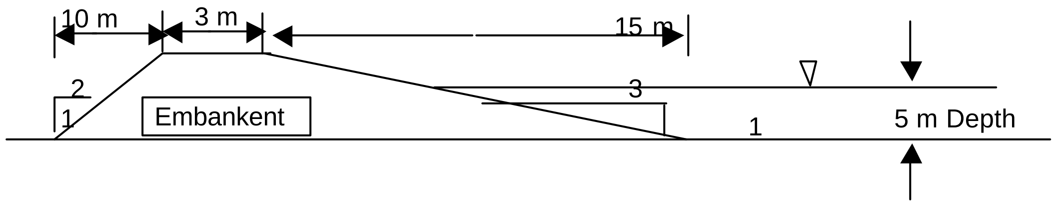
Pipes mm (Dia)	Km	Cost (JD)
400	1	55,000
200	5	150,000
	Total Pipes	205,000
	Misc. Fittings	40,000

Roads / Drainage	Unit Cost (JD / m)
Primary	65
Secondary	30
Track	15

Roads / Drainage	Km	Cost (JD)
Primary	1	65,000
Secondary	3	90,000
Track	4	60,000
	Total Roads / Drainage	215,000

Design of an above ground reservoir

Reservoir volume	18,000	m^3
Embankment length	60	m
Full supply depth	5	m
Embankment crest width	3	m
Embankment height	6	m
Number of embankments	4	



Number of reservoirs	8	
Embankment cross-section	93	m^2
Embankment volume (8)	**178,560**	**m^3**
Substrate clay seal (8)	**51,200**	**m^2**

Table A1. Hydraulics of conveyance pipeline for HL#2a

STATION (m)	GROUND ELEVATION(m)	PRESSURE HEAD REQUIRED FOR LATERALS (m)	TOTAL REQUIRED HEAD AT STATION (m)	FLOW AT STATION (l/s)	DIAMETER (mm)	"C" VALUE	VELOCITY (m/s)	HEADLOSS AT STATION (m)	ENERGY GRADE LINE {EGL} (m)	EGL-PIPE INVERT LEVEL (m)	PIPE INVERT LEVEL (m)
0	550	25	575	1178	900	145	1.5	0	660	112	548
2300	540	25	565	1178	900	145	1.9	5.5	654	116	538
4700	575	25	600	917	900	145	1.4	3.6	651	78	573
5400	570	25	595	917	800	145	1.8	1.9	649	81	568
6400	595	25	620	763	800	145	1.5	1.9	647	54	593
7400	605	25	630	625	700	145	1.6	2.5	645	41	603
8700	605	25	630	317	500	145	1.6	4.8	640	36	604

APPENDIX B
IRRIGATION APPLICATION SYSTEMS

B.1. GENERAL

This document presents an overview of irrigation application systems, their present use in Jordan, their advantages and disadvantages with respect to irrigation with recycled water in the highlands of the Amman-Zarqa, and a recommendation on what techniques are the most suitable.

Selection of an application system requires an inventory of the resources available to the farm, evaluation of the production potential of each resource, and identification of the physical and operational constraints that will affect the selection of a viable irrigation system. Water supply, soil, topography and climate impact the final selection of application systems.

Other factors to be considered are capital and running costs of the systems, the crop type to be grown, degree of automation/labor required, management requirements and practicality of fertigation. Fertigation is the application of fertilizer in the irrigation water. When considering the efficiencies of irrigation application systems it is important to consider that water lost to deep percolation or runoff can be significantly more problematic if it contains fertilizer or even pesticides. In this case, the water supply itself carries potential contaminants.

B.2. IRRIGATION SYSTEM ALTERNATIVES AND EVALUATION

The key decision in defining the irrigation system is that of the application method. There are a wide range of such methods, but these can be generally divided into gravity and pressurized systems. Gravity, or surface, irrigation system range from relatively inefficient spate irrigation to precision-leveled basin irrigation, which can achieve field application efficiencies of over 90 percent. All use the soil surface to convey the water to the plant. Likewise, pressurized irrigation ranges from large gun sprinklers, which spread water over a radius of a wide area, to drip or trickle irrigation which delivers water in small volumes to the base of individual plants.

B.2.1. Surface Irrigation

Surface irrigation is accomplished by one of several application methods, including borders, furrows and basins. In each case water is applied to the soil surface from a channel or pipe located at the upper reach of the field. Inherently surface irrigation systems have relatively low efficiencies because of the low distribution uniformity and the difficulty of controlling surface runoff, although field practices and automation can alleviate the situation.

Surface irrigation (small basins) is practiced in the highlands of the Amman-Zarqa and along the wadi itself (Hanson, 2000). In fact , many of these small basins are supplied water through drip/trickle pipes. This technique can be relatively efficient, but, as noted by Hanson (2000), there can be considerable variation between laterals. Despite the above case, surface irrigation is generally not practiced in the Amman-Zarqa basin.

In general surface irrigation techniques have relatively low efficiencies in terms of water use and require that water be applied in relatively large depths (10-cm). With shallow rooting crops, where small depths of application are required, it is difficult to manage applications efficiently, with much of the water being lost to deep percolation and, eventually, the groundwater.

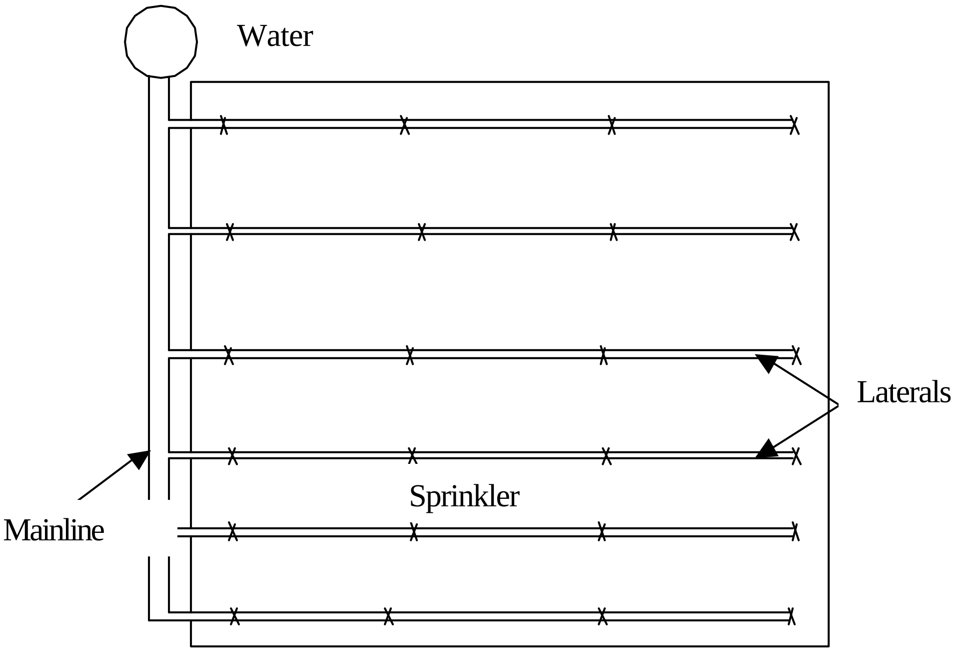
As stated above, surface irrigation techniques are not suitable for shallow rooting crops. However, properly managed surface irrigation is suitable for row crops (furrow) and broadcast crops (border or large basin), and it is relatively inexpensive. The major limitations of concern in this case are the low efficiencies resulting in deep percolation of the recycled water and loss of the resource. Furthermore, the nature of surface irrigation increases the likelihood of field workers coming in contact with the recycled water.

B.2.2. Sprinkler Irrigation

Sprinkler irrigation is the application of water to the soil using a device that directs a stream of water through the air onto the soil. Water is delivered to the sprinkler device through a pressurized pipeline. Water sprayed from a pressurized pipeline into the air breaks into drops, falling to earth like rain. It is particularly adaptable to hilly land where grading for surface irrigation is not feasible.

The sprinkler systems presently available have been developed to cover a wide range of situations and particular problems which include labor saving, improved application efficiency, size and shape of fields, annual vs perennial crops, soil types, quality and quantity of water available, cost of energy, and so forth.

A sprinkler system consists of a mainline, laterals and sprinklers. The sprinklers and risers are connected to the lateral line, sprinkler laterals can be periodically moved from one set position to another by hand, or mechanically sit closely together so the field can be irrigated without moving them. Laterals are installed parallel to the row direction and the mainline perpendicular to the row direction. The mainline may be at one end of the field or through the field.



Because the conveyance of water is through pipes there are negligible losses compared with surface irrigation. However, distribution uniformity and drift of the sprayed water do account for some losses. Typically a well managed sprinkler irrigation system achieves efficiencies of 70 to 80 percent. Because of the improved distribution uniformity with sprinkler systems it is viable to apply shallower applications of water to the field more frequently, which is important on lighter soils which have a relatively low water holding capacity. On heavier soils sprinkler systems have to be carefully design or surface runoff problems will occur.

For the use proposed here, the main concern is with the drift of spray and, to a lesser extent, the distribution uniformity. Furthermore, the spray can leave behind a residual on the leaves or fruit of the plant. The generation of aerosols, although not specifically spelled out in the relevant Jordanian Standards, is typically not acceptable for water reuse. The contact with the field workers is less likely than with surface irrigation techniques.

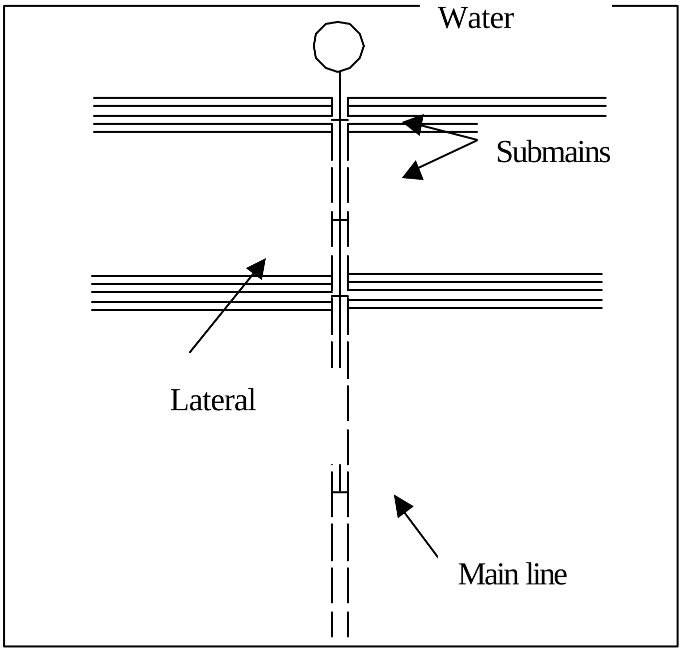
Sprinkler irrigation is generally more efficient than surface irrigation techniques, and can be used to irrigate a wider range of crops, including those that are shallow rooting.

B.2.3. Trickle / Drip Irrigation

Trickle irrigation, unlike surface, which causes wetting of the whole surface of the soil, is a method which causes wetting of only that part of the soil at the base of the plant. The system provides an opportunity for efficient use of limited water because irrigation is limited to the root zone. Using trickle irrigation systems it is possible to attain field application efficiencies of more than 90 percent. Also, because of the ability of the system to deliver small amounts of water efficiently it allows water to be delivered frequently at times that are optimum for the growth of a given crop. It also allows the use of a source of water that has a steady supply, as is the case with recycled water, thereby reducing the need for extra capacity in the conveyance and delivery systems. Trickle irrigation, with its precision deliver of water to the rootzone of plants lends itself to fertigation, but requires careful management.

Only small areas are wetted, thereby minimizing evaporation and runoff. This in turn reduces weed growth. The regular application of small amounts of water means a higher moisture content in the soil which allows the plant to abstract water at relatively higher salt contents.

The system basically consists of a mainline, submains or manifolds, laterals and emitters. The emitters are connected to the lateral line or in some cases are parts of the lateral line. Numerous types of emitters are manufactured; these lateral lines are usually polyethylene (PE) plastic and range in diameter from 8 to 20-mm. Normally these lines are polyvinyl chloride (PVC) pipes. The head works consist of the main control station and may include pumping, filtration and pressure regulating equipment.



Trickle irrigation is becoming increasingly popular in areas with water scarcity and salt problems, as is the case in Jordan. Trickle and drip techniques are widely used in the Amman-Zarqa basin and the Jordan Valley, with much of the necessary equipment, pipes and emitters manufactured in-country.

The two basic techniques used in the highlands of the Amman-Zarqa are, according to Hanson (2000):

- trees irrigated using mini basins about 2 to 3-m in diameter for each tree. Water is supplied by means of a polyethylene tube with an adjustable emitter which can deliver between 50 to 80-l/hr.
- row crops irrigated using drip tubing with emitters spaced every 40-cm, and installed beneath plastic mulch. Typically drip lines are about 50-m.

Because of the small diameter pipes and small orifices within the system, trickle irrigation systems are susceptible to blockages from organic and mineral compounds in the water supply. Because of this rigorous filtering management is necessary to keep the system functioning. This is particularly significant with recycled water. This can be overcome, to some extent, by using low-head bubblers as the emitters, which is similar to the technique already being used by farmers in the highlands.

Trickle and drip irrigation is generally the most efficient application method, although poor management can result in significant losses, particularly for shallow rooting crops. The technique limits the opportunity for workers and crops to come in contact with the recycled water. Sub-irrigation, which is essentially buried trickle laterals, further reduce the opportunity for contact. However, drip/trickle is not suitable for broadcast crops, such as barley, wheat or alfalfa.

B.3. SELECTION

Considering the likely cost of developing recycled water as a source for irrigated agriculture, conservation of that resource is important, as is the need to prevent loss of the recycled water and any fertilizers or pesticides added to the groundwater. Sprinklers are not suitable for recycled water, and surface irrigation techniques, which can be efficient in some cases, are not likely to be efficient in the conditions presented here.

Considering the above, some form of drip or trickle system is the best option for using recycled water in the highlands of the Amman-Zarqa. The limitations are that certain crops, particularly those broadcast, such as barley, wheat and alfalfa, cannot be easily irrigated. Certain variations of the overall system, such as sub-surface irrigation, mini-sprinklers and bubblers need to be considered to allow a wider variety of crops and to minimize the need for filtration.

APPENDIX C
COSTS

Table C.1. Estimate capital costs for HL#2a

Description	Unit	Quantity	Unit Cost (JD)	Amount
A. Mobilization & Demobilization 3% of (B)				**387,664**
Site Preparation	LS	1	150,000	150,000
Land Acquisition (Project Area, Pumping Plant & Pipe)	Km^2	11.0	125,000	1,375,000
Water System				
Pumping				
Pump station for conveyance	LS	1	1,035,262	1,035,262
Pump station for distribution system	LS	10	35,000	350,000
Conveyance System				
Pipes (900 mm) DI + Fittings	m	4700	364	1,710,800
Pipes (800 mm) DI + Fittings	m	1700	322	547,400
Pipes (700 mm) DI + Fittings	m	1000	264	264,000
Pipes (500 mm) DI + Fittings	m	1300	168	218,400
Pipes (300 mm) DI + Fittings	m	1000	98	98,000
Storage				
Earth Embankment	m^3	178,560	6.400	1,142,784
Substrate Clay Seal	m^2	51,200	1.500	76,800
Inlet Works	LS	1	50,000	50,000
Outlet Works	LS	1	125,000	125,000
Distribution System				
Pipes	Km^2	10.2	205,000	2,091,000
Miscellaneous Valves	Km^2	10.2	40,000	408,000
Application System	Dunum	10,000	100	1,000,000
Site Development				
Roads, Drainage	Km^2	10.2	215,000	2,193,000
Agriculture Land Leveling	Km^2	10.2	8,500	86,700
B Sub-total (B)				**12,922,146**
Engineering (Planning, Design & Construction):				
Feasibility (Geotechnical Site Investigation, Survey & Mapping) 5% of (B)				646,107
Design, Tender Documents 10% of (B)				1,292,215
Construction Management 5% of (B)				646,107
C Sub-total (C)				**2,584,429**
D. Sub-total (D)= (A)+(B)+(C)				**15,894,240**
Contingencies				
Design Contingency 10% of (D)				1,589,424
Cost Contingency 10% of (D)				1,589,424
		TOTAL CAPITAL COST =		**19,073,087**

Table C.2. Annual costs for HL#2a

CONVEYANCE ENERGY		
Total dynamic head	112	m
Annual volume pumped	12,330,000	m^3
Average daily discharge	0.39	m^3/s
g	9.81	KN/m^3
Efficiency	75%	
Power	13,747	Kwh/day
Unit cost	0.036	JD/Kwh
Total cost	495	JD/day
Annual energy for conveyance	**180,630**	**JD/annum**
DISTRIBUTION ENERGY		
Total dynamic head	70	m
Annual volume pumped	12,330,000	m^3
Average daily discharge	0.39	m^3/s
g	9.81	KN/m^3
Efficiency	75%	
Power	8,592	Kwh/day
Unit cost	0.036	JD/Kwh
Total cost	309	JD/day
Annual energy for distribution	**112,893**	**JD/annum**
TOTAL ENERGY COST	**293,523**	**JD/annum**
ANNUAL COST OF CAPITAL		
i = 6.5%, 40-yr life		
Total capital cost	19,073,087	JD
Annual cost of capital	**1,348,348**	**JD/annum**
ANNUAL O&M COSTS		
5% of capital costs		
Annual O&M costs	**953,654**	**JD/annum**
TOTAL ANNUAL COSTS	**2,595,525**	**JD/annum**
COST PER CUBIC METER	**0.211**	**JD/m^3**

Note: These costs do not include the on-farm costs fro crop production.

Table C.3. Estimate capital costs for HL#3

Description	Unit	Quantity	Unit Cost (JD)	Amount
A. Mobilization & Demobilization, 3% of (B)				**573,411**
Site Preparation	LS	1	150,000	150,000
Land Acquisition (Project Area, Pumping Plant & Pipe) (note: project area owned by WAJ)	Km^2	1.5	125,000	187,500
Water System				
Pumping				
Pump station for conveyance	LS	1	1,462,500	1,462,500
Pump station for distribution system	LS	7	35,000	245,000
Conveyance System				
Pipes (1000 mm) DI + Fittings	m	11200	422	4,726,400
Pipes (900 mm) DI + Fittings	m	13200	364	4,804,800
Pipes (800 mm) DI + Fittings	m	5900	322	1,899,800
Storage:				
Earth Embankment	m^3	133,920	6.400	857,088
Substrate Clay Seal	m^2	38,400	1.500	57,600
Inlet Works	LS	1	50,000	50,000
Outlet Works	LS	1	125,000	125,000
Distribution System				
Pipes	Km^2	8	205,000	1,640,000
Miscellaneous Valves	Km^2	8	40,000	320,000
Application System	Dunum	8,000	100	800,000
Site Development				
Roads Drainage	Km^2	8	215,000	1,720,000
Agriculture Land Leveling	Km^2	8	8,500	68,000
B Sub-total (B)				**19,113,688**
Engineering (Planning, Design & Construction):				
Feasibility (Geotechnical Site Investigation, Survey & Mapping) 5% of (B)				955,684
Design Tender Documents, 10% of (B)				1,911,369
Construction Management 5% of (B)				955,684
C Sub-total (C)				**3,822,738**
D. Sub-total (D)= (A)+(B)+(C)				**23,509,836**
Contingencies				
Design Contingency 10% of (D)				2,350,984
Cost Contingency 10% of (D)				2,350,984
		TOTAL CAPITAL COST =		**28,211,803**

Table C.4. Annual costs for HL#3

CONVEYANCE ENERGY		
Total dynamic head	122	m
Annual volume pumped	9,648,000	m^3
Average daily discharge	0.31	m^3/s
g	9.81	KN/m^3
Efficiency	75%	
Power	11,717	Kwh/day
Unit cost	0.036	JD/Kwh
Total cost	422	JD/day
Annual energy for conveyance	**153,959**	**JD/annum**
DISTRIBUTION ENERGY		
Total dynamic head	70	m
Annual volume pumped	9,648,000	m^3
Average daily discharge	0.31	m^3/s
g	9.81	KN/m^3
Efficiency	75%	
Power	6,723	Kwh/day
Unit cost	0.036	JD/Kwh
Total cost	242	JD/day
Annual energy for distribution	**88,337**	**JD/annum**
TOTAL ENERGY COST	**242,296**	**JD/annum**
ANNUAL COST OF CAPITAL		
i = 6.5%, 40-yr life		
Total capital cost	28,211,803	JD
Annual cost of capital	**1,994,398**	**JD/annum**
ANNUAL O&M COSTS		
5% of capital costs		
Annual O&M costs	**1,410,590**	**JD/annum**
TOTAL ANNUAL COSTS	**3,647,284**	**JD/annum**
COST PER CUBIC METER	**0.378**	**JD/m^3**

Table C.5. Estimate capital costs for HL#4 conveyance & storage sub-system

Description	Unit	Quantity	Unit Cost (JD)	Amount
A. Mobilization & Demobilization 3% of (B)				**899,790**
Site Preparation	LS	1	150,000	150,000
Land Acquisition (Project Area, Pumping Plant & Pipe)	Km^2	5.5	125,000	687,500
Water System:				
Pumping:				
Pump station for conveyance	LS	2	967,744	1,935,488
Pump station for distribution system	LS			0
Conveyance System:				
Pipes (1200 mm) DI + Fittings	m	40000	653	26,120,000
Storage:				
Reservoir for 100,000 m^3				1,100,000
Distribution System - N/A				
B Sub-total (B)				**29,992,988**
Engineering (Planning, Design & Construction):				
Feasibility (Geotechnical, Site Investigation, Survey & Mapping) 5% of (B)				1,499,649
Design, Tender Documents 10% of (B)				2,999,299
Construction Management 5% of (B)				1,499,649
C Sub-total (C)				**5,998,598**
D. Sub-total (D) = (A)+(B)+(C)				**36,891,375**
Contingencies				
Design Contingency 10% of (D)				3,689,138
Cost Contingency 10% of (D)				3,689,138
		TOTAL CAPITAL COST		**44,269,650**

Main system only. Does not include distribution and modifications to application systems.

Table C.6. Annual costs for conveyance system for HL#4

CONVEYANCE ENERGY - CONVEYANCE ONLY		
Total dynamic head	300	m
Annual volume pumped	10,000,000	m^3
Average daily discharge	0.32	m^3/s
g	9.81	KN/m^3
Efficiency	75%	
Power	29,863	Kwh/day
Unit cost	0.036	JD/Kwh
Total cost	1,075	JD/day
Annual energy for conveyance	**392,400**	**JD/annum**
TOTAL ENERGY COST	**392,400**	**JD/annum**
ANNUAL COST OF CAPITAL		
i = 6.5%, 40-yr life		
Total capital cost	44,269,650	JD
Annual cost of capital	**3,129,587**	**JD/annum**
ANNUAL O&M COSTS		
5% of capital costs		
Annual O&M costs	**2,213,483**	**JD/annum**
TOTAL ANNUAL COSTS	**5,735,469**	**JD/annum**
COST PER CUBIC METER	**0.574**	**JD/m^3**

Note: This is for the conveyance only